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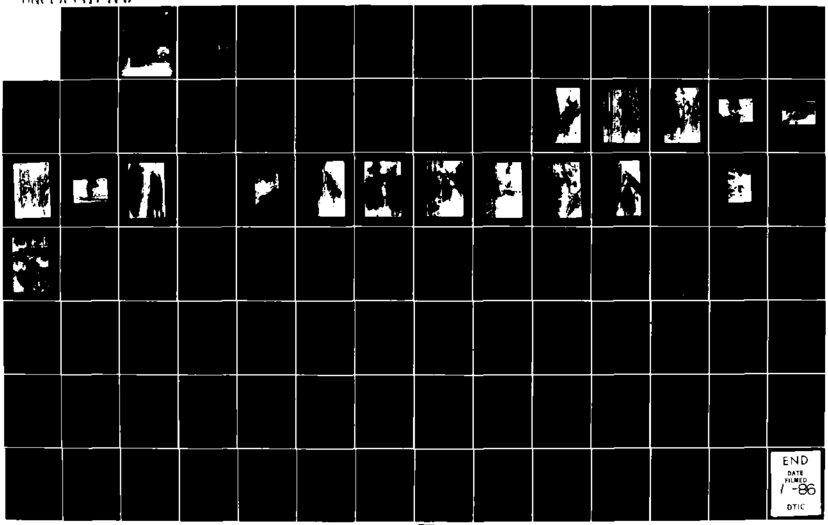

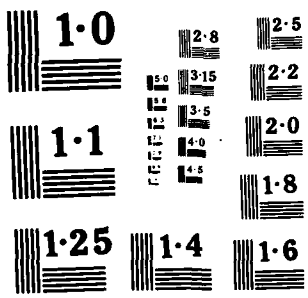
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# FINAL REPORT

## QUALITATIVE EROSION AND SEDIMENTATION INVESTIGATION MALINE CREEK CITY AND COUNTY OF ST. LOUIS, MISSOURI

(1)

FINAL REPORT

QUALITATIVE EROSION AND
SEDIMENTATION INVESTIGATION
MALINE CREEK
CITY AND COUNTY OF ST. LOUIS, MISSOURI

Submitted to

St. Louis District
Corps of Engineers
210 Tucker Boulevard, North
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Prepared by

Simons, Li & Associates, Inc.
3555 Stanford Road
P.O. Box 1816
Fort Collins, CO 80522

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Simons, Li & Associates, Inc. (SLA) has been contracted by the U.S. Army Corps of Engineers (COE), St. Louis District to qualitatively evaluate the sediment transport characteristics of Maline Creek, and assess the effect of the proposed improvements on sediment transport in the creek. Generalized solutions to potential erosion and sedimentation problems are suggested and a literature review of erosion and sedimentation in urban areas is presented. Particular emphasis of the literature review was placed on erosion and sedimentation of loess soils since they are common to the Maline Creek watershed.

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# I. INTRODUCTION

## 1.1 General

Flooding of Maline Creek in and around St. Louis, Missouri has been a problem. In an effort to provide significant flood damage mitigation, increase outdoor recreation opportunities, and enhance the watershed's environmental quality, the U.S. Army Corps of Engineers, St. Louis District has evaluated potential improvement alternatives for the creek. A selected plan for improvement was identified in a 1980 survey report (COE). The recommended plan of improvement consists of the following features:

a. 8 dry detention sites

b. 3.29 miles of channel widening and straightening

c. 5.05 miles of low level floodwalls

d. 3.31 miles of low level levees

e. 91 acres of clearing

f. 5 bridge replacements

g. 2 bridge improvements

h. 18 aquatic habitat structures

i 5 fish ponds

j. 384 acres of open space adjacent to detention basins plus 474 acres along the stream corridor.

k. 10 miles of environmental/recreational trails.

Simons, Li & Associates, Inc. (SLA) has been contracted by the U.S. Army Corps of Engineers (COE), St. Louis District to qualitatively evaluate the sediment transport characteristics of Maline Creek, and assess the effect of the proposed improvements on sediment transport in the creek. Generalized solutions to potential erosion and sedimentation problems are suggested and a literature review of erosion and sedimentation in urban areas is presented. Particular emphasis of the literature review was placed on erosion and sedimentation of loess soils since they are common to the Maline Creek watershed.

## 1.2 Scope of Work

The specific scope of this study is as follows:

1. To review available hydrologic, hydraulic, geologic, geomorphic, soils, and photographic information, and the proposed design data for proposed improvements.

2. To conduct a site visit to familiarize ourselves with the physical environment of Maline Creek and its tributaries. During the site visit, surface samples of bed and bank material will be be collected.

3. To perform a literature review of available information concerning erosion and sedimentation problems in urban areas similar to Maline Creek. Particular emphasis will be placed on loess soils, since their characteristics greatly influence the erosional processes in the watershed. A bibliography will be prepared and copies of the most significant references are to be furnished with the report.

4. To identify the key aspects of erosion and sedimentation of concern to the successful implementation of the preferred alternative. This will be based on the site visit, literature review, and information supplied by the COE. Information to be provided includes identification of major sediment sources, location of areas of bank erosion, historic rates of migration, and qualitative estimates of sediment transport in Maline Creek. Thalweg profiles will be plotted for the 1962 conditions (MSD, 1962) and 1985 conditions (COE, 1985).

5. To review the selected improvement plan for Maline Creek and its compatibility with current erosion and sedimentation conditions along the stream. To make recommendations to minimize erosion and sedimentation problems. Potential problems are to be viewed in terms of operation and maintenance of the project and potential adverse impacts on adjacent property. Major points of consideration are integrity of bank protection, channel bed response to the project, impact on the stability of structures, such as bridges and utility crossings, and impacts on the tendency of the channel to migrate.

6. SLA will provide one copy of a draft report containing the results of the study. After review and comments are received from the Corps, SLA will modify the report if necessary and provide ten copies of the final report. SLA will return all information provided by the Corps.

## 1.3 Data Sources

The analysis presented in this report is based on information collected from several sources. Sources include the U.S. Army Corps of Engineers, St. Louis District, the Metropolitan St. Louis Sewer District, the St. Louis County Highway Department, the State of Missouri Highway Department, and the U.S. Department of Agriculture Soil Conservation Service.

Specific data collected and analyzed for the study include the hydrology of the Maline Creek watershed, channel geometry, HEC-II water surface profile models of exiting and proposed conditions, bed and bank material size distributions, soils information and information describing channel improvements associated with the recommended plan.

Two field trips were made to the Maline Creek watershed to collect data and observe the characteristics of the watershed. Observations were made of watershed development, bridge and pipeline crossings, channelization, bank protection, and locations of significant erosion and sedimentation problems. Samples of bed and bank material were taken in various locations. A summary of observations made during site visits is presented in Chapter III.

A literature search of information related to erosion and sedimentation problems in urban areas similar to Maline Creek was also made. Particular emphasis in the literature search was placed on locating information related to the erosion and sedimentation properties of loess soils typically occurring in the watershed. The sediment transport characteristics of these soils are significant factors determining the behavior of the creek.

# II. LITERATURE REVIEW OF INFORMATION ON EROSION AND SEDIMENTATION IN URBAN AREAS WITH PARTICULAR EMPHASIS ON LOESS SOILS

Erosion and sedimentation due to overland flow, rilling, and gullying are becoming an increasingly significant problem in urban areas. The complex interelation of natural geomorphic processes and man-induced forces involved in urban erosion make fully understanding such processes and their interactions a difficult task. For example, Daniels and Jordan (1966) suggested that gullying is part of the normal evolution of a landscape in thick loessial regions like Iowa and Missouri. In urban areas in particular, man's activities hasten geomorphic processes which accentuate gullying cycles.

In the following discussion, recent work and past studies of the processes of erosion and sedimentation are reviewed. Particular emphasis is given to erosion of loess soils (fine earth soils formed by aeolian deposition) like those found in the Maline Creek area, gully and channel bank erosion, sediment yield in urban areas, and urban erosion problems.

Computer searches of two technical data bases (DIALOG and Colorado Libraries) and the SLA technical library were utilized in locating pertinent information. A bibliography of information cited in this chapter is presented in Appendix A. Copies of reports and abstracts identified in the literature review as being particularly relevant to the erosion and sedimentation processes occurring in the Maline Creek watershed have been presented to the COE separate from this report.

## 2.1 Erosion Studies of Loess Soils

Loess soils are characterized by very uniform, silt-sized particles yellow to brown in color, and varying degrees of cementation. Many studies have been conducted on loess soils throughout the world primarily in response to agricultural needs (Piest and Ziemnicki, 1977, 1979; Smalley and Taylor, 1970). Williams and Allman (1969) studied the factors affecting infiltration and recharge in a loessial watershed in Washington and Idaho. Studies using shallow piezometers installed in the loess indicated that groundwater is recharged during the wet season by infiltration and percolation through the loess. Silty clay loam surface layers control infiltration, and lower horizons of loess often have high infiltration capacities due to larger pore spaces and tubular openings. These hydrologic findings are important in predicting volume of runoff because if soils are saturated due to a high water table, runoff and erosion tend to increase. The authors recommended that erosion can be reduced by surface conditioning to maximize infiltration rates, e.g., surface roughening practices.

Several comprehensive studies on loessial watersheds have been conducted in Iowa. Saxton, et.al (1971) indicated that sheet erosion on agricultural land is severe unless the land surface is nearly level and vegetated. Gully erosion was found to be significant on sloping lands with only partial plant cover. In a study by Piest et.al (1976) gully erosion rates from experimental watersheds averaged two tons per acre annually. Soil losses from sheet-rill erosion averaged at least eight tons per acre annually.

As mentioned above, gullying is a frequent erosion mechanism in the deep loess hills region of Missouri. It degrades land and increases sediment load in local streams. Development of gullies can be grouped into three phases, (1) failure of gully head and gully banks, (2) cleanout of debris by streamflow, and (3) degradation of the channel. Stratigraphy influences gullying because the growth rate of valley bottom gullies and geometry of the walls are controlled by stratigraphic differences in soil strength, permeability, thickness, structural features, and micromorphologic features (Bradford and Piest, 1980; Mucher and De Ploey, 1977). A study by Bradford and Piest in the Missouri River basin indicated that valley side and valley head gullies normally cut through surficial loess (Wisconsin in age). In Missouri the underlying bedrock is Pennsylvanian shales. Extensive widening can then occur, resulting from a decrease in rates of erosion in the shale.

Roloff et.al (1981) conducted a study of throughflow, the flow of infiltrated water above the regional water table, in Howard Roloff County, Missouri. Their study showed that in upper landscape positions, i.e. upland areas above major drainages, throughflow is controlled by buried paleosol (soil) surfaces. Throughflow converges down gradient within a gully wall causing wetter soil conditions and instability. The resulting failure debris is deposited against the valley wall which increases slope stability. Hence, gully development rates were found to be slow and cyclic in the upper landscape positions as a function of intensive rainfall, which renews the process of mass wasting and debris transport.

A diversity of opinion exists concerning the reasons for the stability of steep cuts in loess observed in the field. According to a review by Lohnes and Handy (1968), steep loess slope stability has been attributed to cementation by calcium carbonate, clay and/or clay-water systems, vertical cleavage, secondary carbonate filling vertical root holes, and shrinkage cracks. However, a field study of steep-sided loess banks by Lohnes and Handy indicated that leached loess can hold a steep cut, vertical roots are not ubiquitous in steep cuts, more slopes were observed at 85° angles than at 90° angles, and steep banks are also characteristic of loess-derived alluvium.

To better understand the mechanisms of steep slope stability, Lohnes and Handy studied the shear strength and cohesion of friable loess using soil mechanics methods. The maximum stable heights of steep loess slopes were found to relate to the soil density and shear strength. Estimates of cohesion, variability in vertical and horizontal shear strength, and internal friction angle were used to determine maximum stable heights and slope angles. Results of the sliding wedge method of analysis and field measurements indicated that vertical cleavage of loess appears to be a function of tension in the surface layer, and is not ubiquitous in loess. Vertical slab failure results in a slope angle of approximately 77° and shear failure of a 77° slope results in a slope angle of approximately 51°.

A mathematical evaluation of loessial gully bank stability was completed by Bradford et.al (1973). Primary factors affecting gully stability included water table height, cohesion of the soil, and infiltration rates. Calculated factors of safety indicated that vertical-saturated and near-saturated gully walls will fail in most loess banks if the water table nears the base of the wall and if cohesion is zero at a hydrostatic pressure of zero. Also, failure is influenced by the rate of infiltration in proportion to the hydraulic conductivity of the soil. Soils with high values of conductivity or cohesion will require higher rates of infiltration to develop unstable conditions. Stability was also found to be a function of seepage of subsoil water, changes in electrolyte concentration, and effects of freeze-thaw and wet-dry cycles. Tension cracks present in gully bank materials appeared to play a minor role in slope stability.

Mechanical concepts of gully bank failures were expressed as digital computer programs by Taylor and Johnson (1973). The effects of groundwater on loess soil shear strength and the interaction with gravitational forces were used to evaluate gully bank stability. The reactions of the models to variations in water table heights and changes in cohesion were in accordance with general field experience of slope angles and associated slope failures.

Several detailed studies of physical and chemical properties of loess have been conducted to better understand erosion and chemical transport processes. Alberts et.al (1983) used a rainfall simulator to evaluate characteristics of aggregates eroded from two loess soils in Iowa. The mean diameter of aggregates was found to increase as rilling occurred and larger sizes of the aggregates had proportionately greater amounts of clay and total nitrogen contents.

Nitrogen and phosphorus losses from the Missouri Valley loess watershed were determined by Schumann et.al (1976) and Alberts et.al (1978). At least 85 percent of the losses were associated with the sediment portion of runoff, which were much lower from level-terraced watersheds than from contoured farmed watersheds. This study suggests that loess sediments derived from urbanized areas such as Maline Creek can be expected to carry chemical pollutants as well.

## 2.2 Urban Erosion

Soil erosion is a major environmental and economic issue in the United States and elsewhere. Besides agriculture, urban areas and mining are identified as the next most pervasive nonpoint erosion source in the U.S. (Myers, et.al, 1985). Nonpoint source pollution includes any nonlocalized sediment source areas, such as construction sites and runoff from urbanized landscapes (Mertes, 1984; Powell et.al, 1970)). Topsoil and subsoil loss results in blighted landscapes and sediment loading of downstream waterways. Erosion in urban areas is often associated with large scale developments such as commercial, residential, and industrial projects, which involve massive vegetation and soil manipulation. Smaller projects and runoff from impermeable surfaces in urban areas, e.g. highways and streets, often result in continuous and often pernicious sources of sediment. Confinement of drainageways due to development pressure and increase in runoff associated with impermeable areas often result in degradation of channel beds and accelerated bank erosion.

Of importance in urban watersheds is the volume of stormwater runoff corresponding to available loads of sediment and pollution. According to Dallaire (1976), the following statistics compare the annual soil loss from different land uses: 4 tons per acre from well-established urban areas; 69 tons per acre from disturbed urban areas; 180 tons per acre from any unprotected, graded land. Guy (1970) indicated that clearing and earthmoving activities can increase an area's sediment yield by as much as 40,000 times. Wohman (1975) noted an increase in sediment concentration from construction sites in urban areas on the order of 5 to 200 fold based on data from the United Kingdom, Japan, Canada, and Mexico.

Construction activities in urban areas are particularly important in that intensive sites can contribute more sediment to streams than was previously deposited over several decades. Even a small amount of construction may generate high volumes of sediment due to high soil erosion rates.

In addition to the concern for spatial and temporial erosion at construction sites, Guy (1970, 1974) identified three additional concerns in the field of urban sedimentology, the nature of movement and impact of sediments, methods for mitigating erosion and sediment movement, and channel erosion downstream resulting from increased runoff from impervious surfaces. For example, even though very little erosion may be occurring in the established urban areas surrounding Maline Creek, erosion of channel banks and gully headwalls may be increasing due to increased runoff from less pervious or impervious urban lands.

Maryland has been intensively involved with urban sediment control on a state, county, and municipal level. State programs have been developed and guidance and review has been provided to other government levels. Counties and municipalities have adopted detailed grading and sediment control ordinances (Kanerva and Ports, 1976). Detailed standards for certain structural and nonstructural practices are provided to designers and and contractors, e.g. level spreaders, diversion berms, mulches, chemical tacks and mulch anchoring tools, serrated cuts and scarification. The Wischmeier soil loss equation, discussed in the next section, is the working tool used for estimating erosion from a specific site.

Another example of an urban comprehensive plan is the soil erosion model prepared for the Minneapolis-St. Paul area, Minnesota (Mertes, 1984). Because this twin city area has severe erosion problems and is located adjacent to the Mississippi River, the model has been utilized extensively.

A study by Boesch and Eacker (1972) identified critical sediment problems in the Detroit metropolitan area. Measurements taken during the summer indicated that two percent of the urban zone was under construction and produced 69 tons per acre annually compared to three tons per acre from the remaining 98 percent of the undisturbed urban area.

Finally, the Tahoe Regional Planning Agency in Lake Tahoe, Nevada, has adopted particularly stringent erosion and sedimentation control provisions for governing urban erosion mitigation (Mertes, 1984).

## 2.3 Erosion and Sedimentation Control Measures

Erosion control is the application of certain land treatments to prevent soil exposure to surface processes thereby reducing or completely eliminating sediment loading of wind and water. The literature on erosion control technology is vast and common treatments are summarized by Mertes (1984). Simons, Li & Associates (1983) provided an evaluation of the effectiveness of various structural measures, surface manipulations, and vegetative techniques.

Both structural and nonstructural management practices are available to control urban runoff and erosion. The principal structural alternatives are runoff retention basins, in-line storages, and in-line screens. These methods allow water to percolate into the ground, thereby reducing peak flows and volume of pollutants directly received by streams, or retain water and solids. Nonstructural practices include land use planning, which is the least expensive means of erosion control in developing communities. However, in highly developed urban areas, nonstructural practices as well as structural practices have limited utility and success.

The greatest potential for using the full range of nonstructural and structural practices is in developing communities. For example new developments should employ land use planning techniques to reduce long-term urban runoff volumes. Structural measures can be employed in new and existing developments and industrial areas to mitigate erosion. Similar practices can also be integrated on construction sites. A combination of relatively inexpensive nonstructural vegetative controls, such as seeding and mulching, and more expensive structural measures are often used on construction sites.

Simons (1978) suggests several guidelines for landscape architects, planners, and municipalities which include control of surface runoff by diversions or filling gullies, re-establishing ground cover, and catchment basins.

The principal techniques used in North Carolina are earth berms, slope drains, silt fences, brush barriers, sediment basins, hydroseeding, straw mulch, wood chips and jute netting (Dallaire, 1976). Two major factors considered in choosing a design technique are diversion of runoff before it enters the sites and maintenance of erosion control facilities.

Similarly, Ferguson (1978) noted that erosion control on construction sites requires analysis of boundary flow conditions so that an area can be isolated from surrounding land by a temporary erosion control system.

Specific tehniques have been utilized to control erosion in urban areas. The Universal Soil Loss Equation (USLE) has been adapted to construction sites (Wischmieir et.al, 1971). The equation defines average annual sediment loss in terms of the following factors: erodibility, rainfall, slope, length, cropping and management. The cropping factor has been adapted to landscaped urban areas by Detar et.al, (1980a,b).

Although the USLE has been modified for use in urban areas, this method contains several drawbacks. Harrington et.al (1985) noted that (1) USLE does not estimate the sediment delivery ratio, or fraction of eroded soil entering a stream, (2) the method has yet to stand up to legal challenge as a regulatory tool, and (3) the equation is based on uniform slopes, soil and bare agricultural land, which are not characteristic of urban areas. Therefore, careful consideration of the physical characteristics of the site and critical evaluation are recommended if this method is used on an urban landscape.

Kuo (1976) used a modified USLE to determine sediment yields in Virginia. A dilution factor was studied to correlate the characteristics of a disturbed area with that of an off-site downstream station. The dilution factor was defined as the ratio of suspended-sediment concentration on the site compared to the off-site quality. The dilution factor was found to increase with decreased intensity of rainfall and to vary according to the stage of construction and disturbance.

A physical process computer model was adapted to analyze urban drainage basins by Grover (1983). The model, known as MULTSED2, determines water and sediment yields during single storm events. Input requirements consist of a rainfall hyetograph, a geometric discretization of the drainage basin, and a series of parameters describing the characteristics of the vegetations, soils, and sediment within the basin. Grover's study indicated that the model has a high potential for modeling the water and sediment yields from complex urban drainage basins.

Studies concerning control of erosion on loess soils have been particularly concerned with chemical properties of loess. The effect of exchangeable sodium and gypsum on surface runoff from loess soils in Israel was studied by Keren et.al (1983). Industrial gypsum was found to be very effective in reducing erosion from soils with low and high exchangeable sodium, although most effective on low sodium soils. This is probably due to a reduction in runoff by increasing the infiltration rate and to a change in the erodibility factor, which is related to cohesive forces and aggregate stability. The presence of gypsum increases soil stability by increasing electrolyte concentration in soil water and effecting cation exchange.

Subsurface drainage of loess soils in Washington was found to be very effective in reducing runoff events, according to a study by Lowery, et.al (1982). This study and a recent study by Skaggs et.al (1982) suggested that subsurface drainage should be considered as a possible best management practice for controlling sediment and other pollutants carried by surface runoff on relatively flat land. This non-point source control technique may be particularly applicable on urban land near environmentally sensitive areas where even small amounts of erosion may be objectionable.

# III. SUMMARY OF MALINE CREEK SITE VISIT

On April 2, 1985, a site visit of Maline Creek was conducted. Participants in the site visit were Mr. Fred Bader (Corps of Engineers) and Mr. Bill Fullerton (Simons, Li & Associates, Inc.). The site visit covered primarily the main channel from its confluence with the Mississippi River to the point where the Creek flows under I-70. The purposes of the site visit were to observe the general condition of the creek in terms of its erosion and sedimentation behavior, identify any important factors that may influence the proposed flood control project, and collect sediment samples. A second visit was conducted on April 24 to observe Blackjack Creek.

This chapter presents the general observations and conclusions concerning the behavior of Maline Creek derived from the site visit.

## 3.1 General Observations

During the site visit, some important observations were made pertaining to conditions along Maline Creek. These observations are grouped into several categories describing physical properties of the creek. The categories include urbanization, bed characteristics, and bank characteristics.

### 3.1.1 Urbanization

Except for a very small fraction of the watershed that is being used for open space or the remnant of agricultural activities, the entire watershed has been urbanized. This has influenced the channel through the numerous bridges, bank protection and sewer line encasement in the channel or the adjacent flood plains. The sewer line encasements are discussed further in Section 3.1.2 and bank protection in Section 3.1.3. Urbanization has increased the amount of runoff that the channel must convey. It is the interaction of these features, as well as the pre-existing characteristics of the watershed, such as topography, soils, geology, vegetation, and climate, that determine the response of the channel.

In terms of the effects of increased runoff, the impact on the channel has been the introduction of increased instabilities as the channel tries to reach a new equilibrium with the modified hydrologic regime. Instabilities created include increased bank instability and potential downcutting of the channel. The former is a result of the channel adjusting its size and shape to convey larger flows. The latter is a consequence of the increase in flow velocity and possibly a reduction in sediment supply once the initial land disturbance associated with construction has disappeared.

The most significant direct alteration of the channel by urbanization has occurred in the area of Lucas and Hunt Road. A 0.7 mile distance of channel was cut off and relocated due to the alignment of the road. The design for the relocated channel was a 2H:1V trapezoidal channel. No bank protection was provided. In this realignment area the channel banks are eroding on the right bank as indicated in Figure 3.1. Degradation is also appearing at the upstream end due to the steepening of the slope by the cutoff. Approximately three or four feet of fall occurs at the base of the sewer line encasement just above the upstream end of the cutoff; this is depicted in Figure 3.2. Another indicator of degradation is the fact the old channel is perched two to three feet at the upper end of the cutoff. Figure 3.3 illustrates the point where the old channel branches from the cutoff. This photograph was taken at the upstream end of the cutoff.

### 3.1.2 Channel Bed Characteristics

The Maline Creek channel bed is comprised mainly of silts and clays with some fine sands. Within many of the reaches the bed also contains a significant amount of rubble and stone that has washed into the channel from nearby bank protection efforts (Figure 3.4a and 3.4b). Significant quantities of sand and gravel are present on the bed only in some of the upper reaches of the channel, in the area of I-270. The origin of the gravel is unknown, since the soil surveys for the watershed do not indicate any major occurrence of this material in the watershed. It is possible that the gravel was derived from fill placed along the banks or from highway construction activities.

Portions of the bed consist of exposed clays that the channel has incised. The flow has scoured deposited material or debris from the bed in these areas. Only at one location was there evidence of a shalely rock outcrop. This feature is located several hundred yards downstream of Lewis and Clark Boulevard (Figure 3.5).

Other than the single geologic control and the exposed clay, the only other occurrences in the channel that offer resistance to degradation are the numerous concrete sewer line encasements and the drop structure located just upstream of Riverview Road (Figure 3.6a and 3.6b). During the site visit approximately ten locations were observed where the sewer line encasements

Figure 3.1. Channel erosion near Lucas and Hunt Road.

(Photograph of south bank looking upstream approximately 200 feet upstream of Lucas and Hunt Road Bridge)

Figure 3.2. Sewer line encasement upstream of Lucas and Hunt channel cutoff.

(Photograph looking at south bank approximately 1000 feet upstream of Lucas and Hunt Road Bridge)

Figure 3.3. Abandoned channel caused by cutoff of meander bend.

(Photograph of south bank approximately 600 feet upstream of Lucas and Hunt Bridge)

Figure 3.4a. Rubble used for bank protection has fallen into the channel and covers the bed of many parts of Maline Creek.

(Photograph looking downstream from Florissant Road)

Figure 3.4b. Rubble used for bank protection has fallen into the channel and covers the bed of many parts of Maline Creek.

Figure 3.5. Shale outcrop along Maline Creek near Lewis & Clark Blvd.

(Photograph taken approximately 750 feet downstream of Lewis & Clark Blvd. Bridge)

Figure 3.6a. Exposed sewer line encasement.

Figure 3.6b. Drop structure above Riverview Road.
(Photograph looking downstream)

were exposed. In most cases, the water plunged two to three feet on the downstream side of the these structures. At several of the locations rubble or stone had been dumped on the downstream side to protect against scour.

In general, the composition of the channel bed is largely a result of the material that has been placed along the banks or in the bed as a consequence of the development of the watershed. There is little if any of the bed that could be considered in a natural alluvial state.

3.1.3 Bank Characteristics

The banks of Maline Creek are composed primarily of loess with very low-clay content for the upper 10 to 15 feet. Below this, a layer of high-clay content loess or stiff clay occurs. The exposure of the more cohesive soils is most frequent in the middle and upper reaches of Maline Creek above Bellefontaine Road. The loess portions of the bank are at extremely steep slopes, usually on the order of 1.0 horizontal to 1.0 vertical, or steeper. The clayey portions were flatter at about 2:1. Figure 3.7 illustrates a typical bank as just described.

Bank erosion is occurring at numerous locations. The erosion appeared to be as much the result of geotechnical conditions in the loess as hydraulic conditions. Typically, bank erosion was occurring as a result of slope failure. It appeared that saturation of the soils in the late winter and early spring had induced some of the failures. The material was deposited at the toe of the slope, often with the vegetation still partially intact (Figure 3.8). During significant flows, the material will be removed from the toe and carried downstream. This is a common erosion cycle for loess streambanks.

To retard or prevent bank erosion, numerous residents and businesses along Maline Creek have installed bank protection. The majority of the protection is in the form of dumped revetment, which usually consists of rubble rather than stone (Figure 3.9a). Other forms of protection included grouted riprap (Figure 3.9b), gabions (Figure 3.9c), toe protection (Figure 3.9d), and concrete lining (Figure 3.9e). Bank protection has produced varying degrees of success. For the most part, the success of the protection has been a function of the degree of sophistication and proper engineering practices applied to the site. The majority of the bank protection consists of rubble dumped over the bank in problem areas. This protection may have arrested bank erosion, but judging from the profuse amount of rubble in the bed adjacent to and

Figure 3.7. Typical banks along Maline and Blackjack Creeks. Upper 10-15 feet is loess. Below this is found a loess material with a much higher clay content.

(Photograph looking upstream along Maline Creek approximately ½ mile upstream of Florissant Road)

Figure 3.8. Bank failure along Maline Creek.

Figure 3.9a. Concrete rubble placed along banks of Maline Creek.

Figure 3.9b. Grouted riprap along Maline Creek.

Figure 3.9c. Gabions along Maline Creek.

Figure 3.9d. Riprap with wire toe protection.

(Photograph looking downstream from West Florissant Road)

Figure 3.9e. Concrete-line portion of Maline Creek.

downstream of this type of installation, any success experienced at these sites has been tne result of continuously dumping additional supplies of rubble on the bank. The bank protection that is performing the best is located on Blackjack Creek adjacent to the Meadows School. The bank along this reach has been graded to an approximately 3H:1V sideslope. The protection on the sideslope consists of angular riprap that had been placed over filter fabric. At the crest of the slope a small concrete drainage channel is located for collecting and disposing of local drainage, which would otherwise flow over the channel bank or infiltrate into the channel sideslope. No appreciable damage had occurred to the protection and vegetation had started growing between the rock.

In general, bank protection along Maline Creek and its tributaries has proceeded on a piecemeal basis with protection being added in localized areas whenever a problem arises. Protection measures installed by most private land owners do not appear to have involved any sort of design effort. Often they have been installed improperly or inappropriate materials have been used.

## 3.2 Conclusions

Based on the site visit, several conclusions were made concerning the behavior of Maline Creek. The two most prominent processes occurring in the channel that may affect future flood control projects are bank erosion and channel degradation. Of these two, the former is most significant. Bank erosion appears to be a common problem throughout the system, and although rates are not very rapid, the proximity of development to the banks makes even small amounts of erosion a potential problem (Figure 3.10). The other significant process, channel degradation appears to have occurred in the channel on the order of three feet in recent times. The degradation probably resulted from the increased runoff induced by urbanization. However, channel degradation will not proceed very rapidly in the future due to several factors. First, the watershed has been almost completely urbanized, therefore discharges should not continue to increase (detention ordinances should help alleviate this problem from any areas that still remain to be developed). Secondly, the channel has incised its bed down to a more erosion-resistant layer of clay or clayey loess. Finally, the sewer line encasements, if maintained, should act as grade controls and help stabilize the vertical profile of the channel.

Related to bank erosion, and of great importance to the overall design of the project, are the loess soils, which comprise the majority of the

Figure 3.10. Minor amounts of bank erosion would endanger this structure.

flood plain and channel banks. This material is easily eroded and has unique geotechnical properties. Special considerations must be given to drainage flowing over the banks and on developing stable sideslopes for any channelization measures. Figure 3.11 illustrates the significant erosion of the banks that can occur from even minor local drainage developed over unprotected banks.

Deposition of sediments or aggradation is not a problem in the channel. There are few bars or other evidence of deposition in the channel. This is consistent with the fact that there is minor amounts of sand or coarse material in the watershed. The channel has a more than adequate capacity to transport the finer materials that are present.

Figure 3.11. Bank erosion resulting from minor local drainage over the banks.
(Photograph taken of north bank of Maline Creek approximately 300 feet upstream from Lucas and Hunt Bridge)

# IV. QUALITATIVE ANALYSIS

## 4.1 General

The purpose of conducting a qualitative analysis of erosion and sedimentation tendencies along Maline Creek is to identify the general sediment transport characteristics of the Maline Creek system and to identify the potential impacts of improvements associated with the recommended plan. Possible means of avoiding or mitigating negative impacts can then be made. The importance of the qualitative approach is its ability to identify the general tendencies of the stream system and to quickly assess the response of the system to change. At a later date, the reasonableness of more technical approaches may then be more readily assessed as to the validity of their results.

The qualitative analysis utilizes various sources of information to assess system response to change. Historical records, aerial photographs, site visit information, and the hydraulic properties of the existing system are analyzed to identify the stability characteristics of the stream, geologic controls and general tendencies of the system.

As background information the hydrology, soils, and geology are also discussed in this chapter. Qualitative assessment of the effect of each on sediment transport along Maline Creek is made.

## 4.2 Hydrology

The Maline Creek watershed has a total drainage area of approximately 25 square miles, and is a tributary to the Mississippi River. Their confluence is located south of the community of Bellefontaine Neighbors. The annual average precipitation of the watershed is 37 inches and is fairly evenly distributed throughout the year. The watershed exhibits a moderately well-developed, dentritic drainage network with a moderately high drainage density.

Maline Creek has eight major tributaries. The names and approximate drainage areas of the streams are listed in Table 4.1. Blackjack Creek is the largest tributary with approximately 28 percent of the drainage area of Maline Creek. The second largest tributary is Gall Creek, contributing about eight percent of the Maline Creek drainage area. The remaining six tributaries each contribute between three and five percent of the total drainage area.

The Maline Creek flood plain is subject to flooding of relatively short duration and highly variable severity. Flooding is primarily due to high

Table 4.1. Tributaries to Maline Creek.

| Tributary Name | Designation from* 1980 Survey Report | Drainage Area (Square Mile) | Percent of Maline Creek Watershed Area (%) |
|---|---|---|---|
| Riverview Branch | MA | 1.1 | 4.4 |
| Bellefontaine Branch | MB | 1.2 | 4.6 |
| Moline Acres Branch | MC | 0.9 | 3.4 |
| Blackjack Creek | MD | 7.2 | 28.3 |
| Ferguson Branch | ME | 0.7 | 2.8 |
| Ball Creek | MF | 2.0 | 8.0 |
| Ferguson Branch | MG | 1.3 | 5.3 |
| Kinlock Branch | MH | 0.9 | 3.4 |

*Designation is an alternative means of identifying tributaries to Maline Creek.

intensity rainfall from thunderstorms. High intensity rainfall results in flood problems due to the rapid development of runoff caused by the low permeability loess soils and high percent of impervious urban lands found in the watershed. High intensity rainfall can occur at anytime of the year in the St. Louis area, although severe storms are most likely to occur during a four-month period from May through August. The topographic features and well-developed drainage system in Maline Creek generally prohibits storms of low intensity and long duration from causing extensive flooding of the flood plain areas of Maline Creek.

Three flow gaging stations are located in the Maline Creek watershed. Significant lengths of records, however, do not exist at the gages for frequency analysis of flood flows. In the 1980 survey report (COE) a rainfall/runoff simulation model (HEC-1) was used to develop flood flows along the stream for rainfall of various return periods. Table 4.2 shows the discharges for the 10- and 100-year floods at various locations along Maline Creek for existing and proposed channel improvement conditions and future expected development conditions of the watershed. No information is available on flood discharges for existing development conditions.

## 4.3 Geology and Soils

### 4.3.1 Geology

Maline Creek drains a highly urbanized loessial watershed. The local relief of the gently to moderately sloping drainage is less than 300 feet and the mean slope of the longest reach of the creek is about one foot of vertical drop in 220 feet.

The watershed lies within the Till Plains section of the Central Lowlands physiographic province. Structural features in the area include anticlines and synclines associated with the Ozark Dome to the west and the Illinois Basin to the east.

The highest bedrock in the basin consists of gently sloping shales and limestones of the Pennsylvanian Maramton or older Cherokee Group, (COE, 1980). Shales were observed during the site visit in only one location along the bed of Maline Creek, several hundred yards downstream of Lewis and Clark Boulevard (U.S. Highway 67). Below these formations are cyclical deposits of interbedded limestone/dolomites, sandstones and shales overlying Precambrian rocks at depth (3000 feet).

Table 4.2. 10- and 100-year Return Period Flood Discharges at Various Locations Along Maline Creek for Future Expected Development Conditions.

| Location | 10-year Existing Channel Conditions (cfs) | 10-year Proposed Channel Conditions (cfs) | 100-year Existing Channel Conditions (cfs) | 100-year Proposed Channel Conditions (cfs) |
|---|---|---|---|---|
| Below Riverview Branch Tributary (MA) | 12,210 | 13,257 | 22,440 | 23,991 |
| Below Bellefontaine Branch Tributary (MB) | 12,390 | 13,633 | 21,900 | 24,102 |
| Below Moline Acres Tributary (MC) | 12,380 | 13,607 | 21,680 | 23,773 |
| Below Blackjack Creek Tributary (MD) | 12,300 | 13,515 | 21,440 | 23,214 |
| Below Ferguson Branch Tributary (ME) | 7,900 | 8,343 | 13,580 | 13,548 |
| Below Ball Creek Branch Tributary (MF) | 6,870 | 7,420 | 11,530 | 11,783 |
| Below Ferguson Branch Tributary (MG) | 5,970 | 6,251 | 9,710 | 10,086 |
| Below Kinlock Branch Tributary (MH) | 5,190 | 5,142 | 7,540 | 7,549 |

4.3.2 Soils

Surficial material consists of a thick (30 to 50 feet) deposit of Quaternary loess. Loess is a windblown, glacial age silt deposit, some of which has been reworked by fluvial processes forming silty alluvium on flood plains and terraces. Two distinct loess formations have been recognized by the Missouri Geological Survey (Lutzen and Rockaway, 1971): the Peoria loess which is 5 to 10 feet thick and the underlying clay-rich Roxana loess which is 20-30 feet thick. Downward migrating moisture commonly collects at this interface because of the decreased permeability of the lower loess.

According to a study by the Corps of Engineers (1980) borings indicate that the stratigraphy of the surficial deposits are very similar. The soils and sediments consist of interbedded silts and clays overlying shale at a depth of 5 to 25 feet. More detailed descriptions of the soils as defined by the Soil Conservation Service (1982) are given below.

The soils of this watershed are formed in loess and nearly all are used for urban development. The Urban Land-Harvester Complex comprises about 70 percent of the Maline Creek watershed, mainly in the upland areas. About 10 percent of the channel and flood plain is comprised of Fishpot-Urban land Complex. The Menfro Silt Loam and the Menfro-Urban Land Complex each comprise roughly 10 percent of the area and a few percent include several series such as the Freeburg Silt Loam, Winfiled Silt Loam, and the Blake-Eurdora-Waldron Complex.

The Urban Land-Harvester Complex includes a range of soils on ridge tops and sideslopes of upland valleys in the Maline watershed. Slopes range from 2 to 9 percent and are moderately well drained. Urban lands, including streets, parking lots, and buildings comprise about 60 percent of the complex. The Harvester Series occurs with urban lands in a mosaic pattern and is a silt loam and silty clay loam mainly composed of fill material. A buried, firm silt loam occurs within three feet of the surface.

The soil type forming the channel and floodplain of most of Maline Creek and the lower reaches of some of the tributaries is the Fishpot-Urban Land Complex. This complex is nearly level to gently sloping and poorly drained. Most of the floodplain and adjacent terraces have been built up with fill material for urban use, however rare flooding does occur. Urban lands compose about 40 percent of the complex. The topsoil of the Fishpot Series is a dark grayish brown, friable silt loam underlain by a multicolored fill material with a firm, silt loam buried soil at depth.

The Menfro Silt Loam occurs on about 10 percent of the upland sideslopes. Most of the series occurs on steep slopes and is well drained. The brown and yellowish brown silt loam and silty clay loam are stratified and clay increases with depth.

The Menfro Silt Loam also occurs intermingled with urban lands. The Menfro-Urban Land Complex occurs on sideslopes of small side drainages of Maline Creek on slopes between 5 and 20 percent. About 35 percent of this complex includes urban lands.

A small portion of Maline Creek valley is composed of Freeburg Silt Loam. This poorly drained, gently sloping soil occurs on a few stream terraces and abandoned portions of the floodplain. Escarpments or short slopes are common along the lower boundary of this complex.

Finally, two soils make up only a small few percent of the watershed, the Winfield Silt Loam which occurs on steeply sloping, moderately well drained sideslopes and on narrow ridgetops and the Blake Complex. The complex consists of poorly-drained dark grayish brown silty clay loam, fine sandy loam and silty clay. It occurs at the mouth of Maline Creek on the flood plain adjacent to the Mississippi River. Flooding of this complex ranges from frequent to rare depending on the degree of flood protection in the area.

### 4.3.3 Soil Samples

Soil samples of bed and bank material were taken at five locations along Maline Creek during the site visit. Figure 4.1 shows the approximate location where samples were taken. Analysis of the samples was made to determine their size distribution. Hydrometer analysis was utilized to determine the distribution of material passing the 200 sieve (.075 mm). Gradation curves developed for each sample are presented on Figure 4.2.

The gradation curves for all the samples show that they are composed of approximately 70 to 90 percent by weight of material finer than the No. 200 sieve (.075 mm). Sample numbers 1, 2, 3, and 4 were taken of bank material along the creek. Sample No. 5 was taken of the stiff erosion resistant clay found in the bed of the channel. This may be correlative with the lower loess formation, the Roxana Loess, discussed in Section 4.3. Sample No. 5 was found to be composed of the finest material.

The clay content determined for each sample was found to be between 4 to 7 percent by weight. From field observations, it is believed that the clay

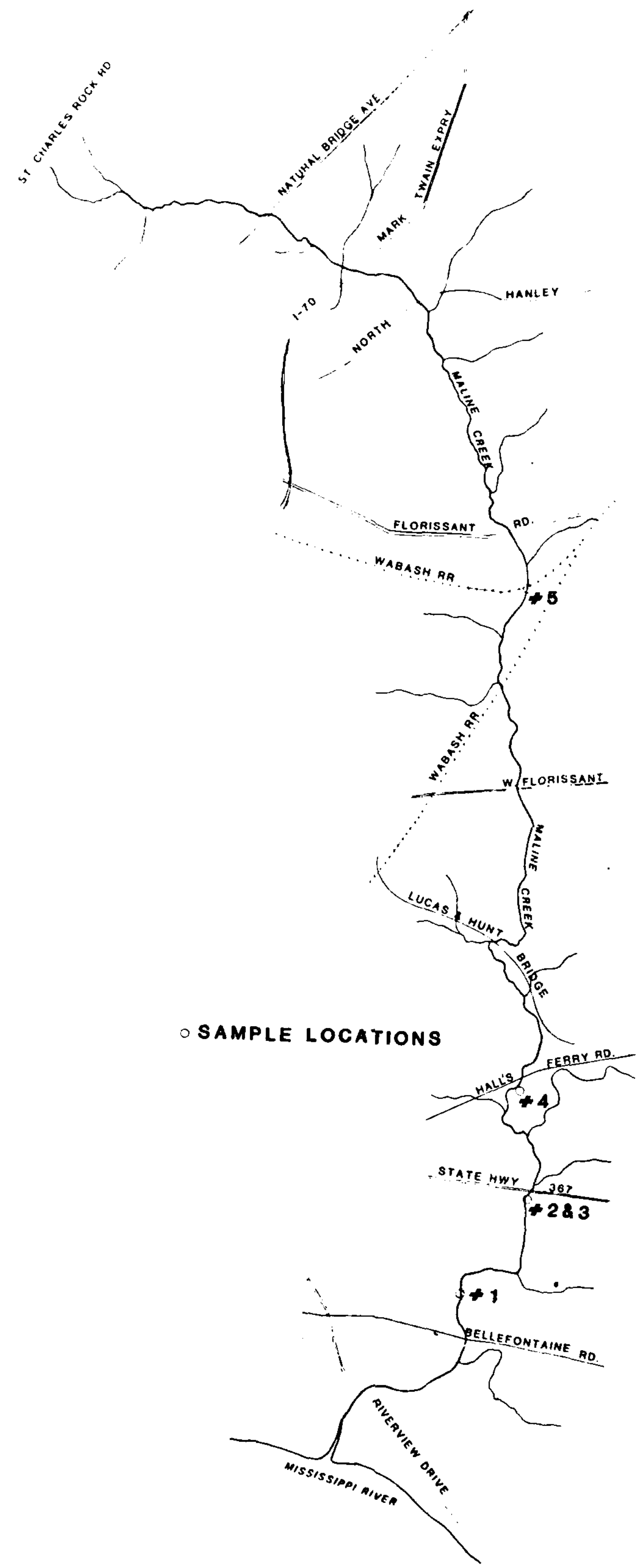



Figure 4.1. Locations of soil samples in Maline Creek watershed.

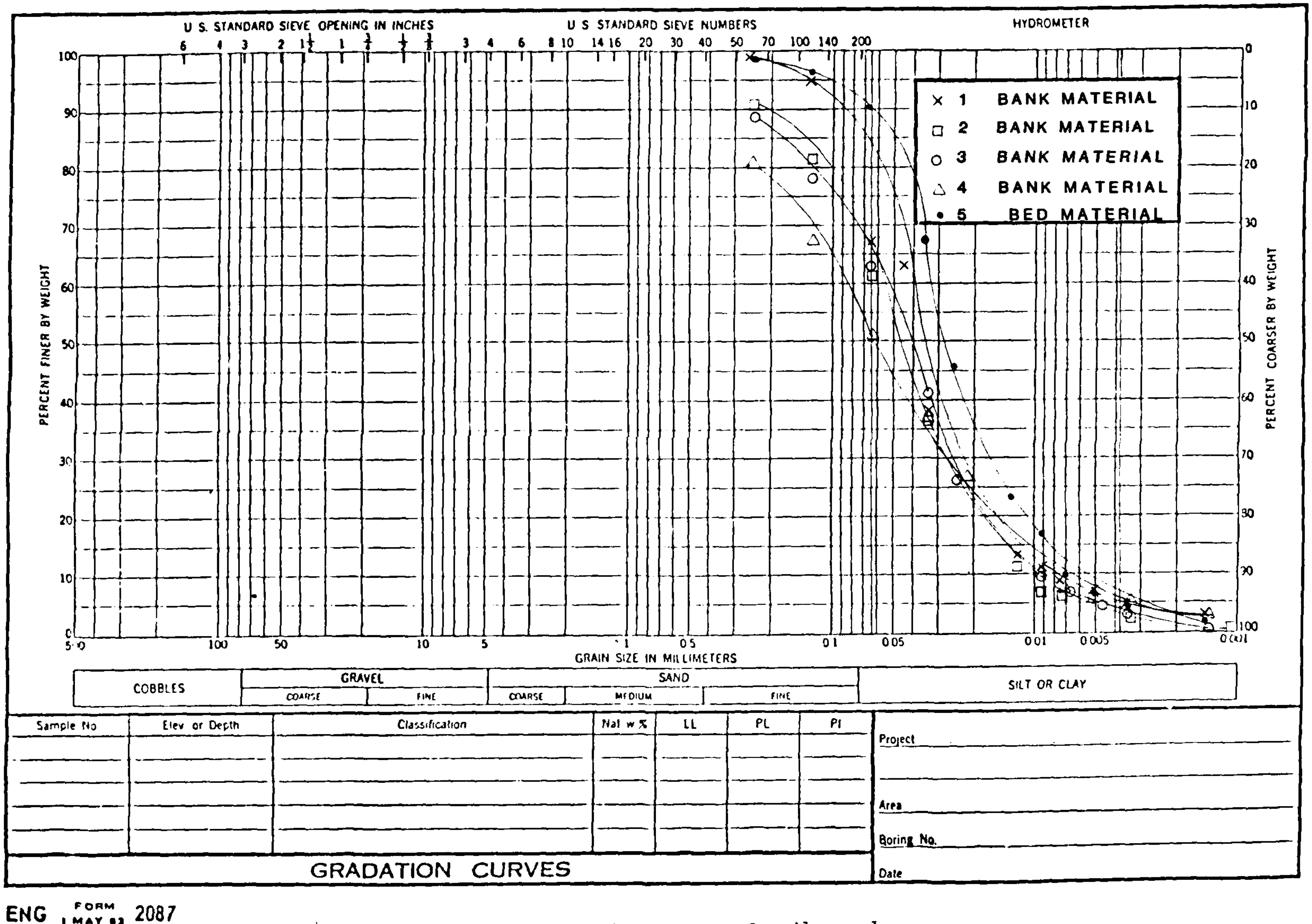



Figure 4.2. Gradation curves of soil samples.

content is actually higher, on the order of 20 percent by weight. The low clay content determined by the hydrometery analysis is thought to be due to inadequate dispersion of clay particles.

## 4.4 Profile Comparison

### 4.4.1 Maline Creek

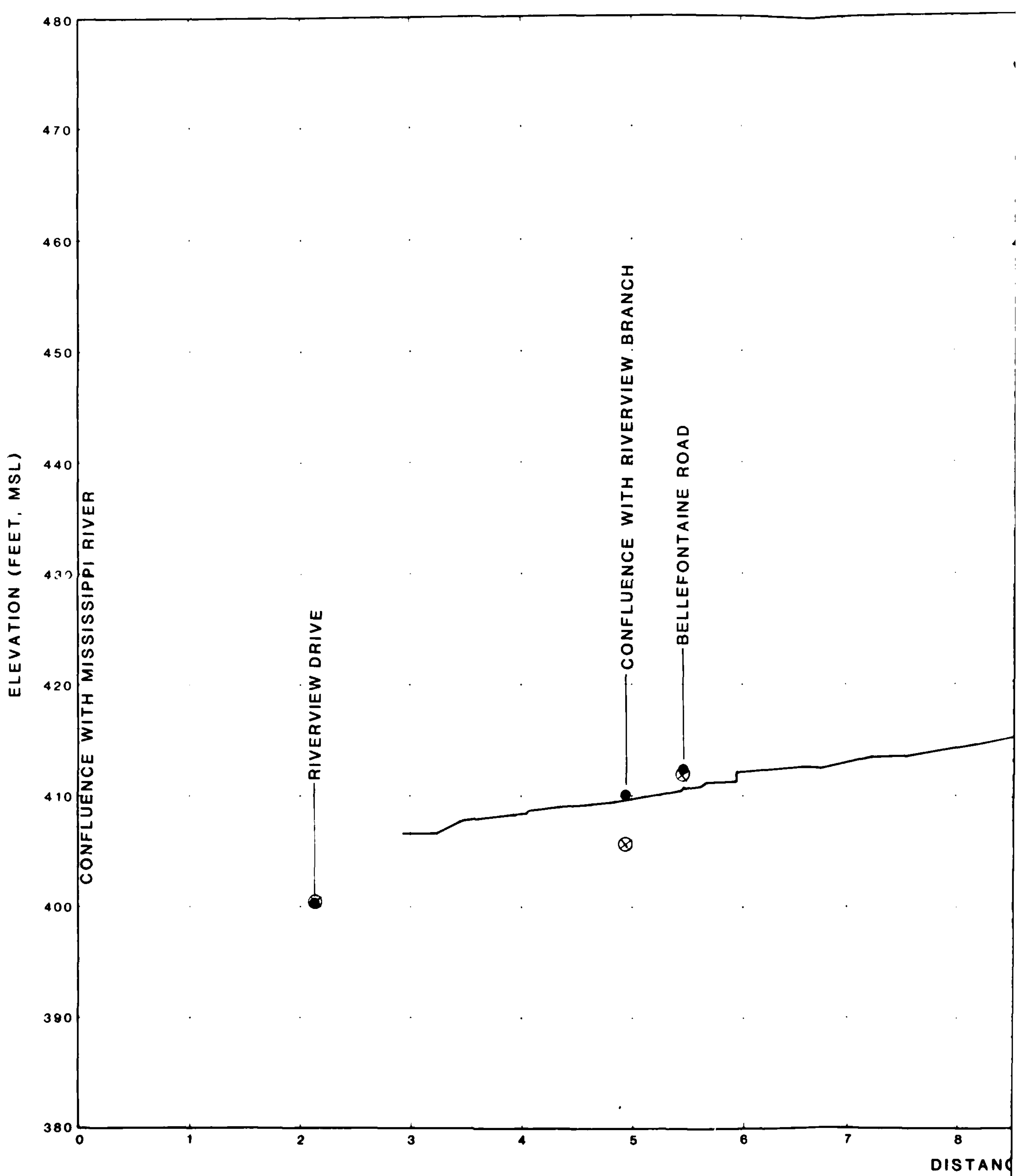
Comparison of historic channel profile data for Maline Creek was made to identify locations of significant erosion or deposition and long-term trends of the channel. Site visit observations were utilized to verify findings of the profile comparison.

As can be seen in Figure 4.3a, the general trend of Maline Creek is an overall degradation of the channel profile. The channel bed has eroded between one to three feet over most of its length. The overall erosion of the channel profile indicates a deficit of available sediment compared to the transport capacity of the stream. The large amount of urban area in the watershed has reduced available sediment and increased the runoff and consequent sediment transport capacity of the stream.

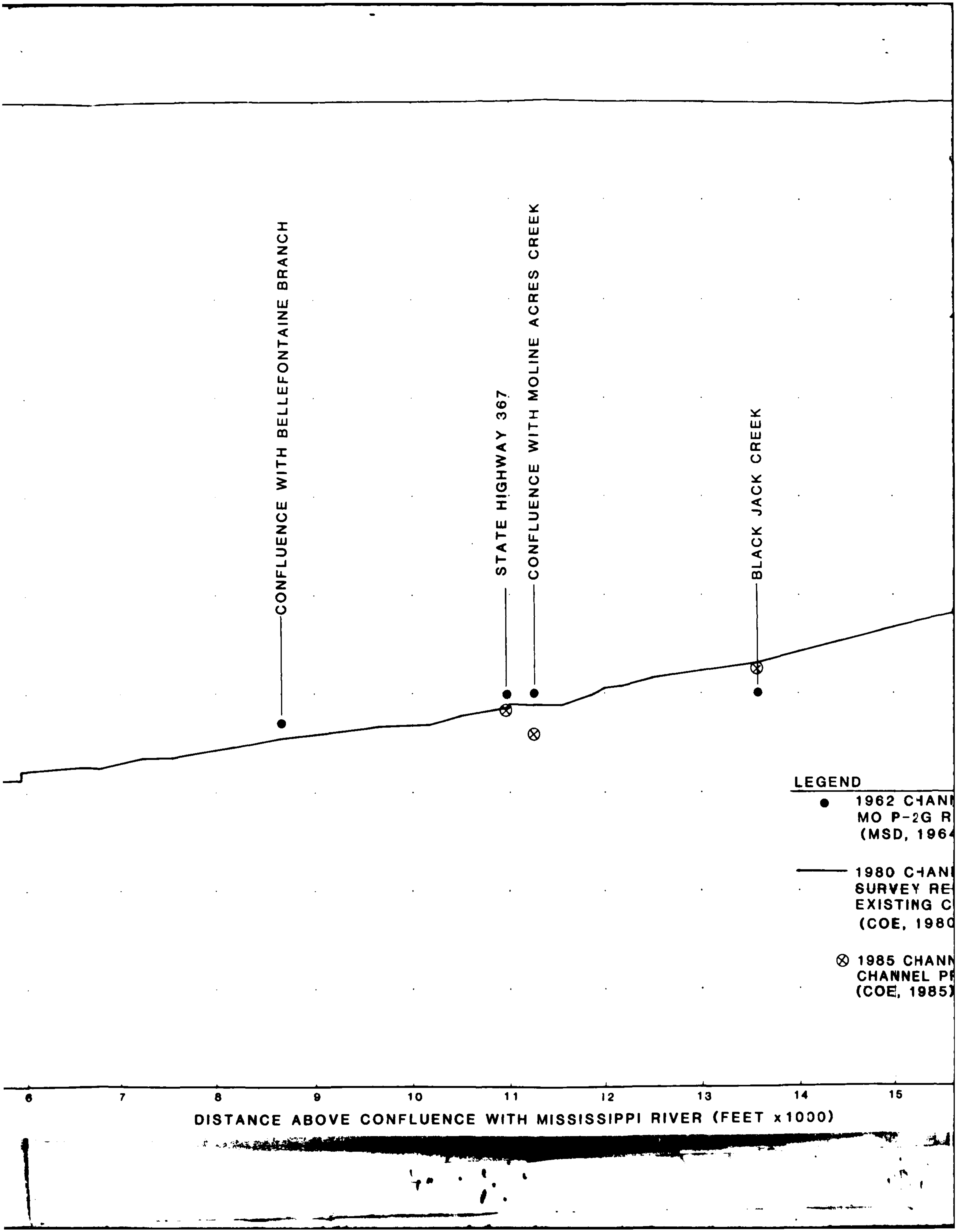
At the confluence of Blackjack Creek, the channel was found not to be following the overall trend of channel degradation. The channel invert has aggraded approximately four feet in this area. This is believed to be a localized condition. The amount of sediment supplied by bank erosion occurring along Blackjack Creek is apparently greater than the sediment transport capacity of Maline Creek at their confluence, thus causing the observed change in bed elevation.

At Glen Owen Drive the channel bed has degraded approximately twice as much as was generally observed throughout the profile. The 1980 channel was seen to be approximately seven feet lower than that observed in 1963. This change is due to the cutoff downstream of a meander bend made during construction of the Lucas and Hunt Road extension. The length of the channel in this reach changed from a natural length of 3,600 feet to a channelized length of 1,800 feet. The shortening of the channel has steepened the slope causing higher channel velocities and increased erosion of the channel.

Field observations made during the site visit confirm this situation. The natural channel at the upstream end of the cutoff is perched approximately three feet higher than the active channel bed elevation. Another drop of approximately three feet was also seen a short distance upstream at a concrete



480
470
460
450
440
430
420
410
400
390
380
ELEVATION (FEET, MSL)
CONFLUENCE WITH MISSISSIPPI RIVER
RIVERVIEW DRIVE
CONFLUENCE WITH RIVERVIEW BRANCH
BELLEFONTAINE ROAD
0
1
2
3
4
5
6
7
8
DISTANC



CONFLUENCE WITH BELLEFONTAINE BRANCH
STATE HIGHWAY 367
CONFLUENCE WITH MOLINE ACRES CREEK
BLACK JACK CREEK
LEGEND
1962 CHANN
MO P-2G R
(MSD, 1964
1980 CHANI
SURVEY RE
EXISTING C
(COE, 1980
1985 CHANN
CHANNEL PI
(COE, 1985)
6
7
8
9
10
11
12
13
14
15
DISTANCE ABOVE CONFLUENCE WITH MISSISSIPPI RIVER (FEET x1000)

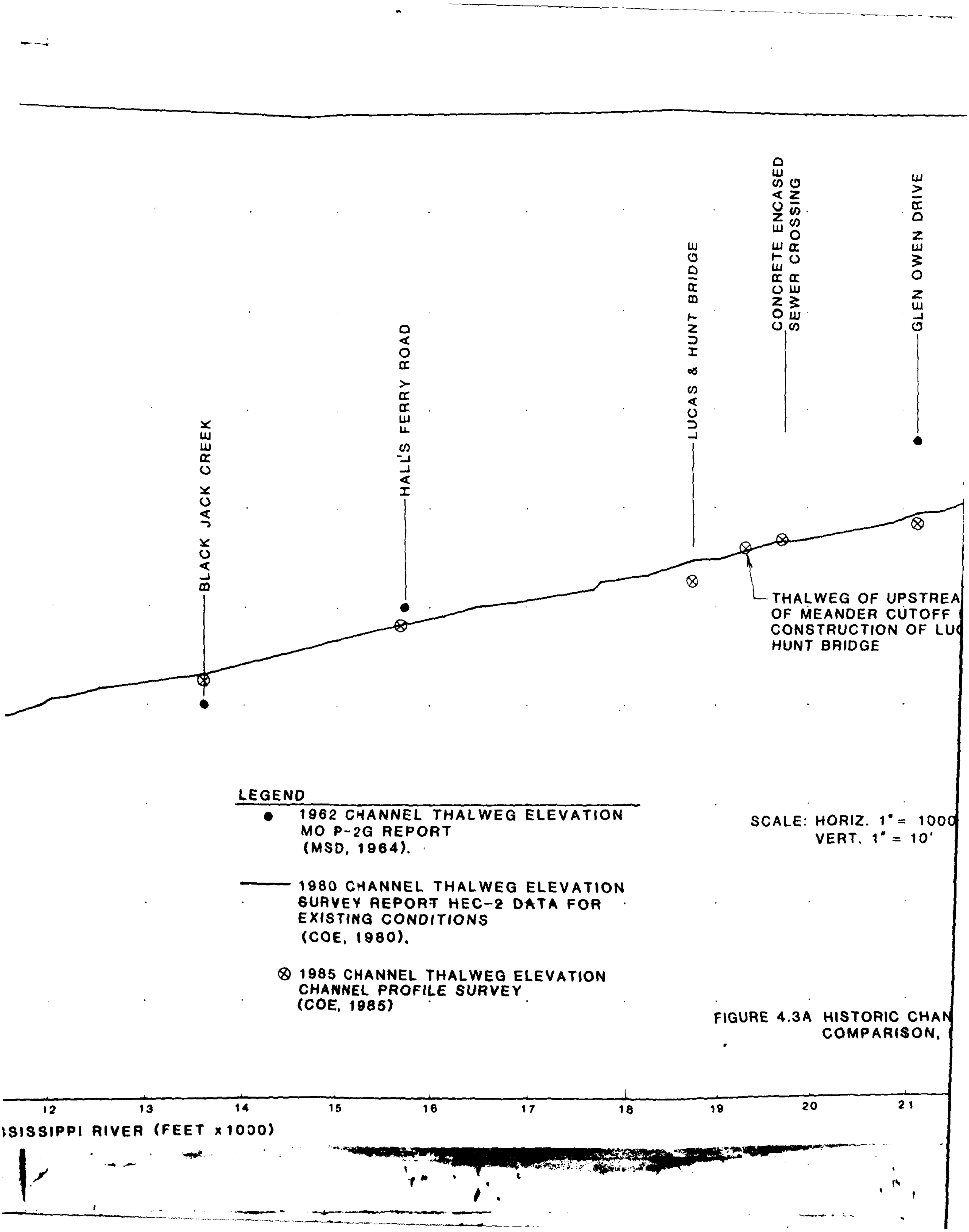



FIGURE 4.3A HISTORIC CHAN
COMPARISON,

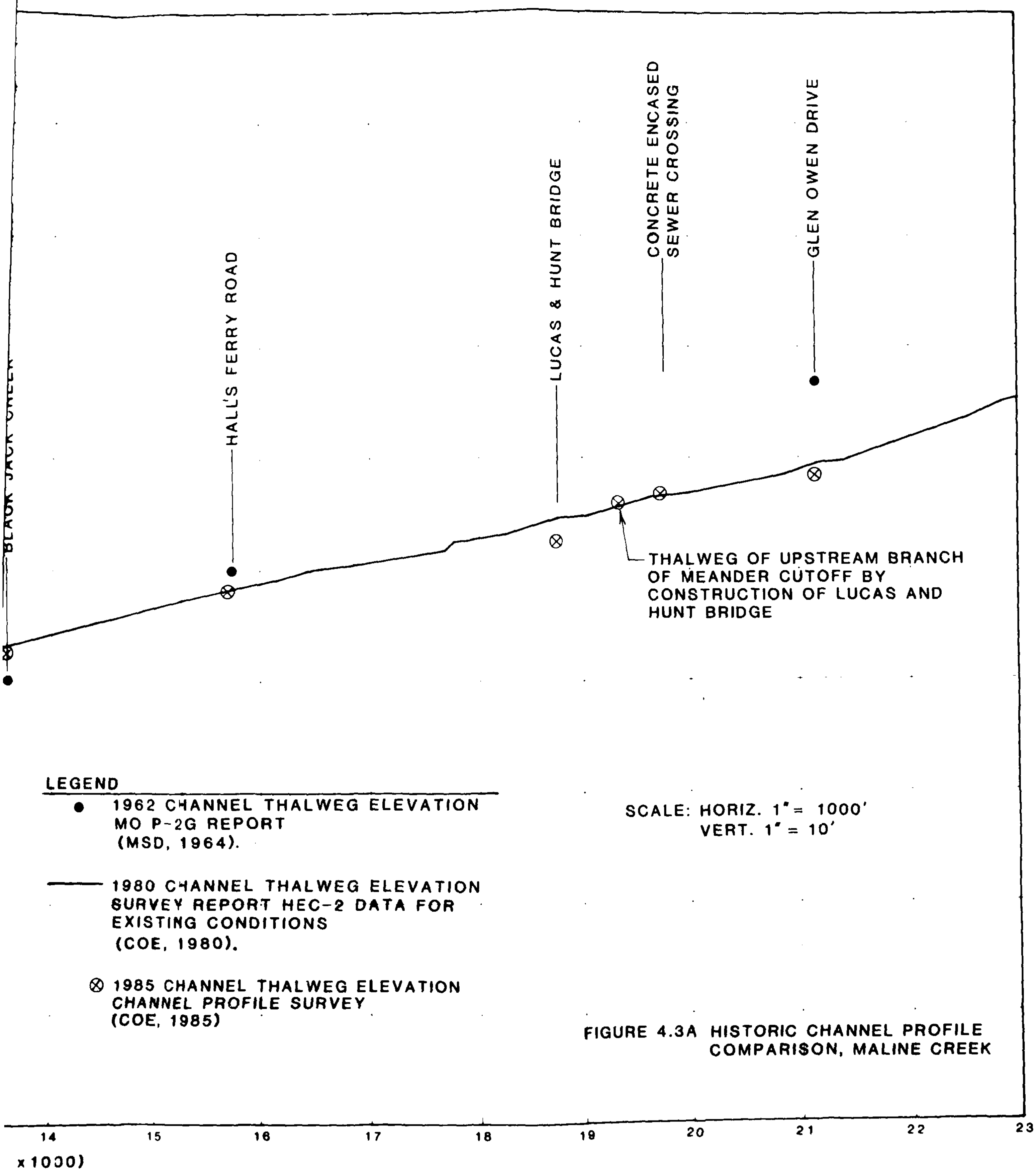
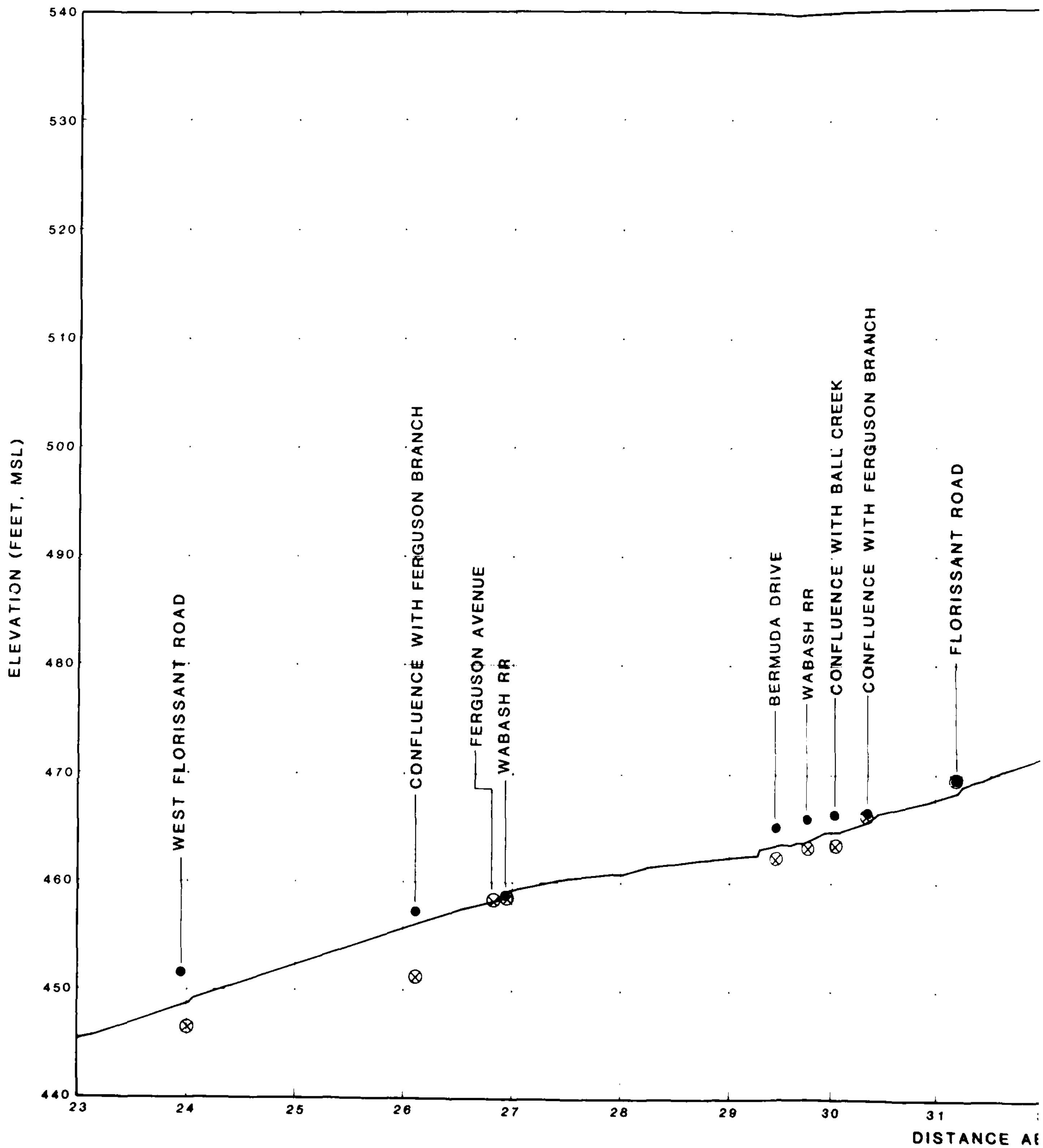
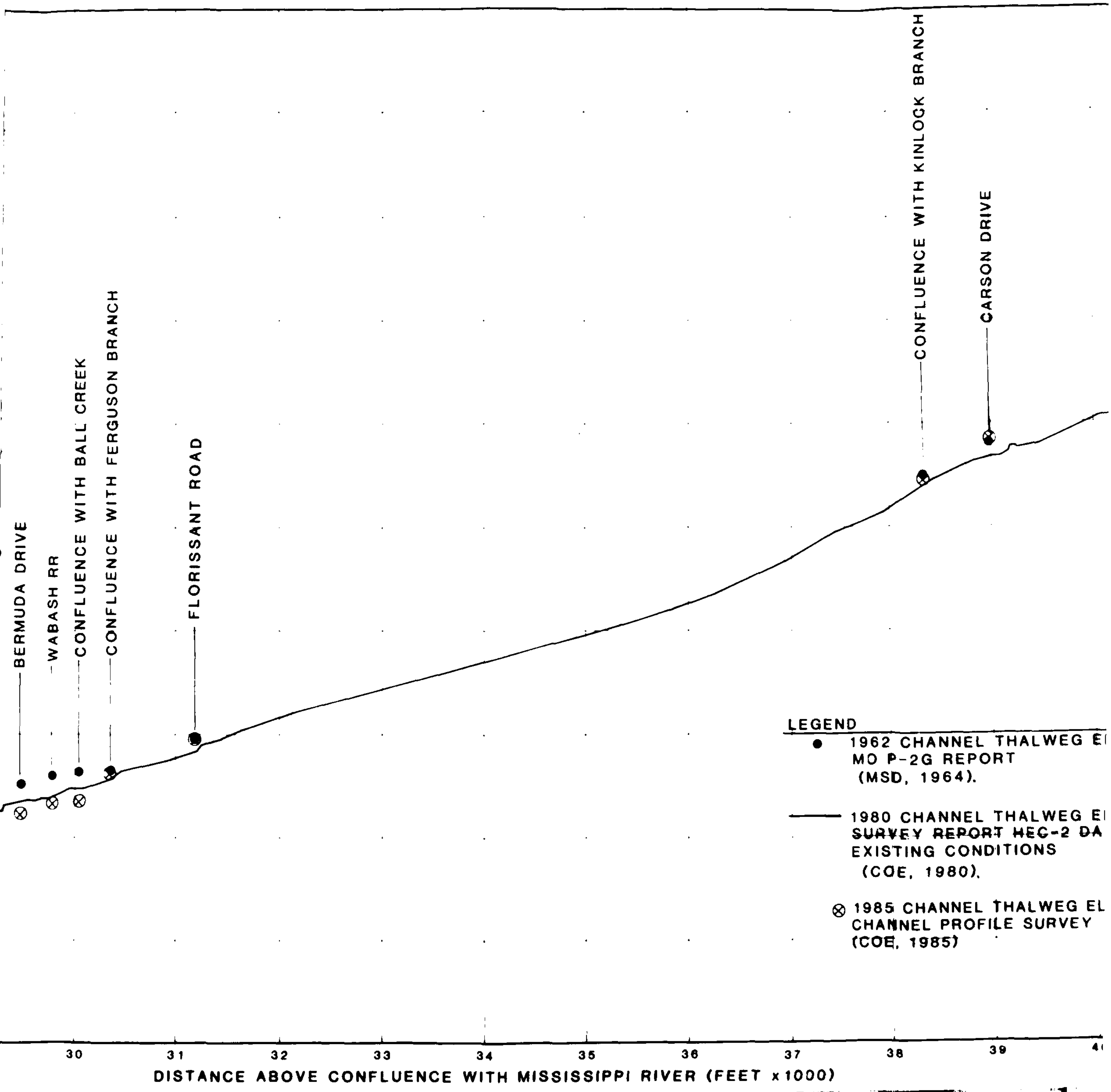



FIGURE 4.3A HISTORIC CHANNEL PROFILE COMPARISON, MALINE CREEK



ELEVATION (FEET, MSL)
540
530
520
510
500
490
480
470
460
450
440
23
24
25
26
27
28
29
30
31
DISTANCE AB
WEST FLORISSANT ROAD
CONFLUENCE WITH FERGUSON BRANCH
FERGUSON AVENUE
WABASH RR
BERMUDA DRIVE
WABASH RR
CONFLUENCE WITH BALL CREEK
CONFLUENCE WITH FERGUSON BRANCH
FLORISSANT ROAD



BERMUDA DRIVE
WABASH RR
CONFLUENCE WITH BALL CREEK
CONFLUENCE WITH FERGUSON BRANCH
FLORISSANT ROAD
CONFLUENCE WITH KINLOCK BRANCH
CARSON DRIVE
LEGEND
1962 CHANNEL THALWEG E
MO P-2G REPORT
(MSD, 1964).
1980 CHANNEL THALWEG E
~~SURVEY REPORT HEC-2 DA~~
EXISTING CONDITIONS
(COE, 1980).
1985 CHANNEL THALWEG EL
CHANNEL PROFILE SURVEY
(COE, 1985)
30
31
32
33
34
35
36
37
38
39
DISTANCE ABOVE CONFLUENCE WITH MISSISSIPPI RIVER (FEET x 1000)

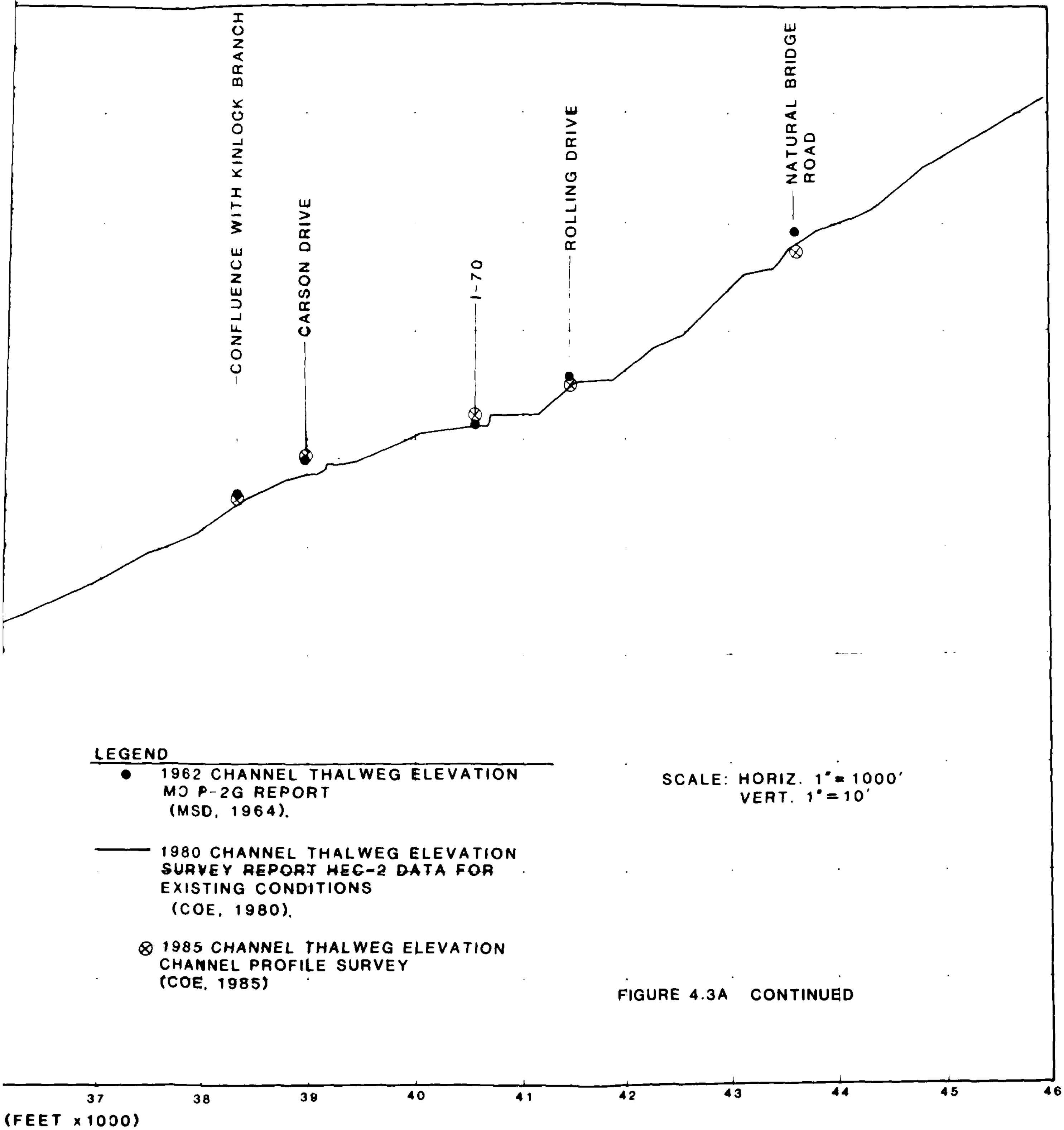



FIGURE 4.3A CONTINUED

encased sewer line crossing. A drop of about two feet was seen at an exposed pipeline crossing on the downstream side of Glen Owen Drive.

The drops observed at pipeline crossings in the Glen Owen Drive/ Lucas and Hunt area indicated that these structures are acting somewhat like grade control structures. The amount of degradation that might have occurred through this reach if these structures did not exist is estimated to be between three and five feet.

At two locations the channel bed elevation was seen to be essentially the same between 1962 and 1980, the Wabash railroad bridge upstream of Ferguson Drive and at the I-70 box culvert.

No historic information on the elevation of the channel bed at the shale outcrop downstream of Lewis and Clark Boulevard is available. Site visit observations indicated that the outcrop may have only recently been exposed by degradation of the channel. A drop of approximately 2 to 3 feet was observed downstream of the outcrop. The fall occurring over the outcrop is typical of drops observed at exposed line crossings.

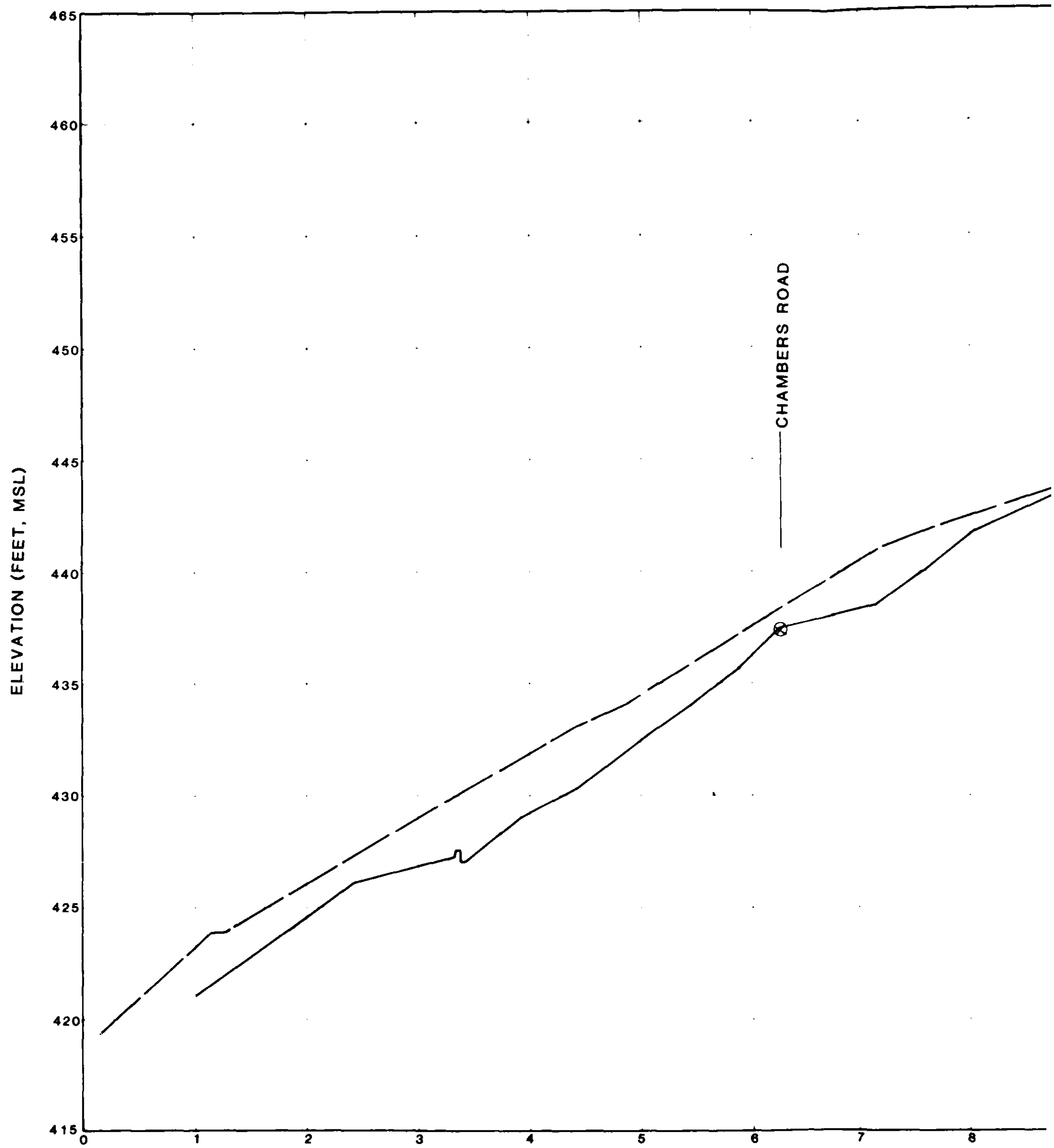
The 1985 channel profile data (COE, 1985) was also plotted on Figure 4.3a. As can be seen, it generally agrees with the observations made from comparison of 1962 and 1980 channel data. Overall, degradation of between 1 to 3 feet has occurred over most of the channel. At the confluence with tributaries, the largest amount of degradation was observed.

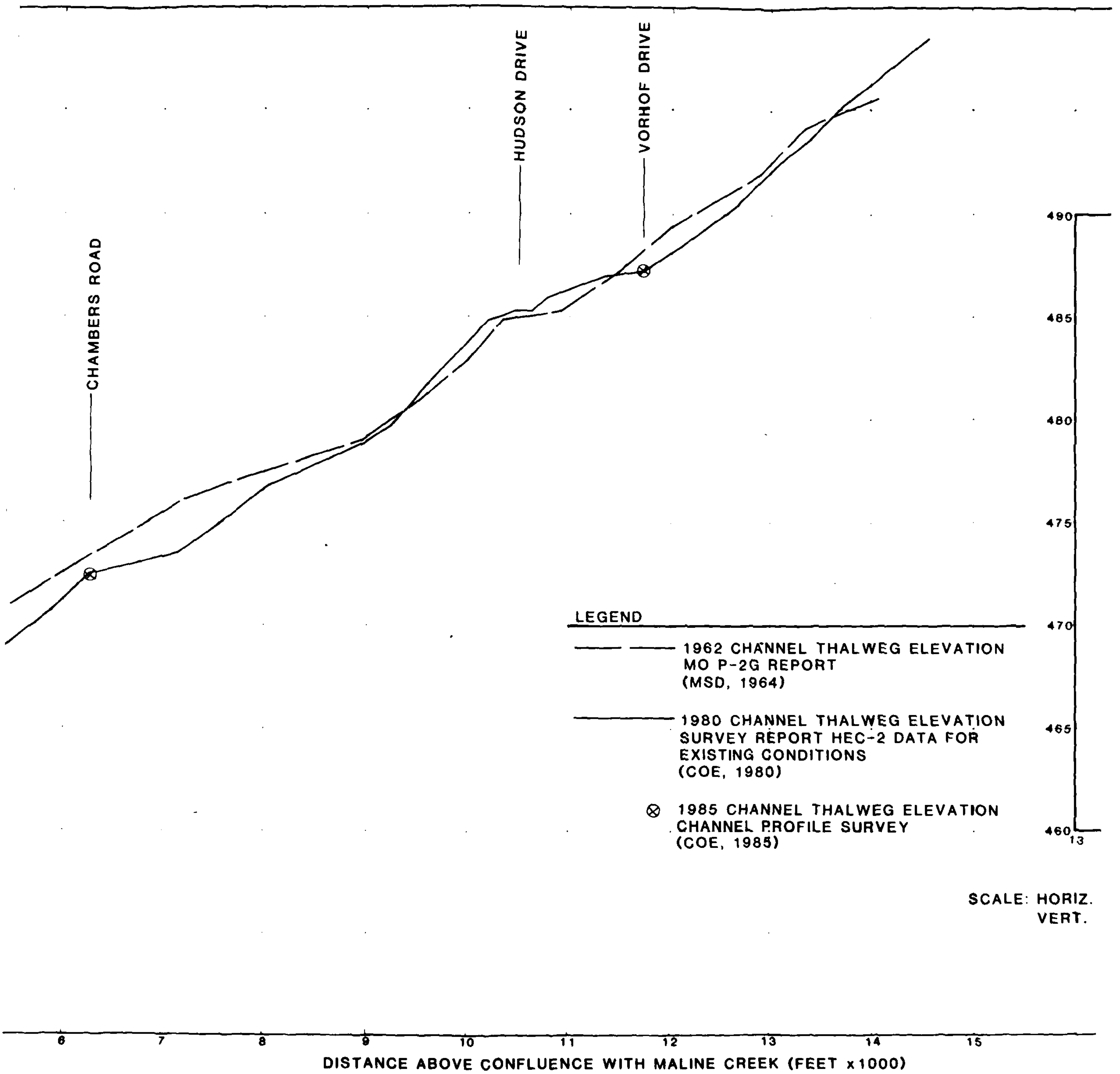
Only slight increases in degradation were observed between 1985 and 1980 channel data. This is thought to be due to an erosion-resistant clay layer which the channel has incised over much of its length. Additionally, the numerous concrete encased sewer lines which cross the creek tend to act as grade controls.

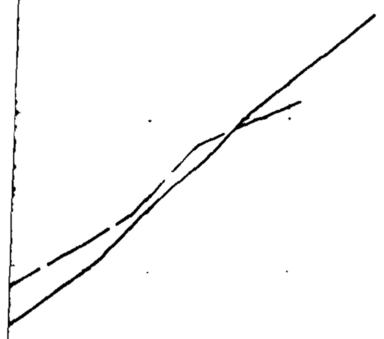
### 4.4.2 Blackjack Creek

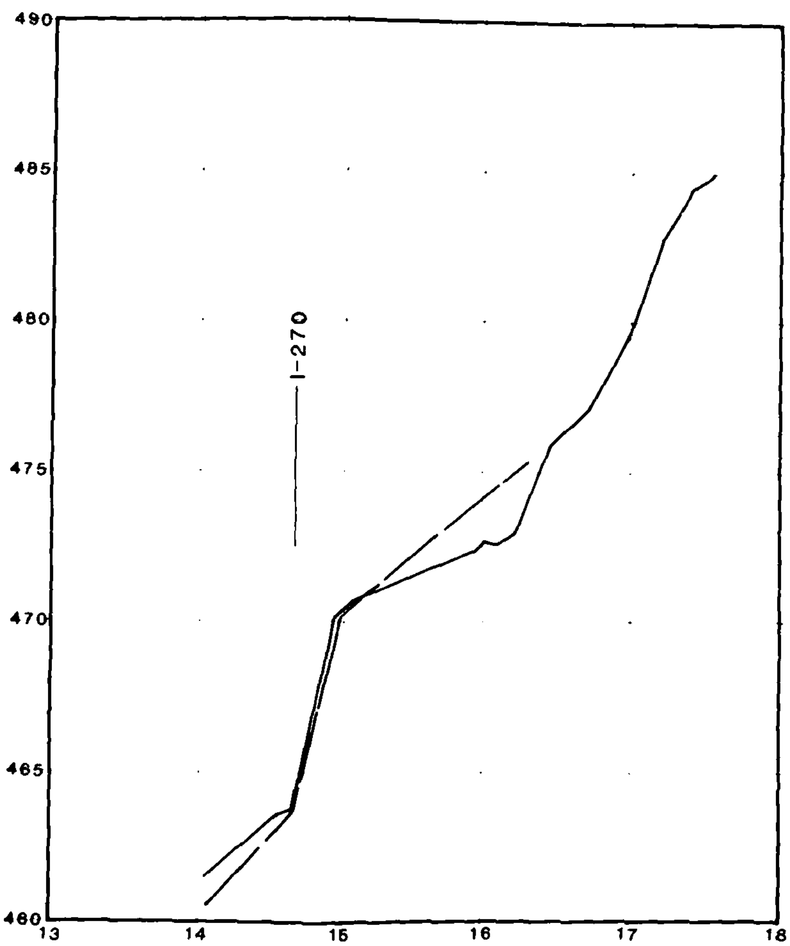
Comparison of historic channel profile data for Blackjack Creek was also made, since it is the largest tributary to Maline Creek.

As can be seen in Figure 4.3b, the general trend of Blackjack Creek is an overall degradation of the channel profile. Similar to Maline Creek, the channel bed has eroded between one to three feet over most of this length. The overall erosion of the channel profile indicates a deficit of available sediment compared to the transport capacity of the stream.


ELEVATION (FEET, MSL)
465
460
455
450
445
440
435
430
425
420
415
CHAMBERS ROAD
0
1
2
3
4
5
6
7
8


CHAMBERS ROAD
HUDSON DRIVE
VORHOF DRIVE
490
485
480
475
470
465
460
13
LEGEND
1962 CHANNEL THALWEG ELEVATION
MO P-2G REPORT
(MSD, 1964)
1980 CHANNEL THALWEG ELEVATION
SURVEY REPORT HEC-2 DATA FOR
EXISTING CONDITIONS
(COE, 1980)
1985 CHANNEL THALWEG ELEVATION
CHANNEL PROFILE SURVEY
(COE, 1985)
SCALE: HORIZ.
VERT.
6
7
8
9
10
11
12
13
14
15
DISTANCE ABOVE CONFLUENCE WITH MALINE CREEK (FEET x1000)






- 1962 CHANNEL THALWEG ELEVATION
MO P-2G REPORT
(MSD, 1964)

- 1980 CHANNEL THALWEG ELEVATION
SURVEY REPORT HEC-2 DATA FOR
EXISTING CONDITIONS
(COE, 1980)

1985 CHANNEL THALWEG ELEVATION
CHANNEL PROFILE SURVEY
(COE, 1985)

SCALE: HORIZ. 1" = 1000'
VERT. 1" = 5'

FIGURE 4.3B HISTORIC CHANNEL PROFILE COMPARISON
BLACKJACK CREEK

2 13 14 15

ALINE CREEK (FEET x1000)

The large amount of degradation observed agrees with the aggradation observed at the confluence of Maline Creek and Blackjack Creek. The amount of sediment eroded from Blackjack Creek is apparently greater than the transport capacity of Maline Creek causing aggradation of the Maline Creek channel near their confluence.

Comparison of 1985 and 1980 channel data revealed no significant change. Again, this is thought to be due to the erosion resistant clay layer into which the channel is now incised and the numerous pipeline crossings which tend to act as grade controls.

## 4.5 Aerial Photographs

Comparisons of aerial photographs taken of the Maline Creek watershed in 1964 (COE, 1964), 1971 (SCS, 1971), and 1985 (COE, 1985) were made to identify areas of significant channel changes, to determine historic rates of channel migration and to relate changes in the watershed to channel changes. The 1964 aerial photographs are at a scale of 1 inch equals 2,000 feet, the 1971 photographs have a scale of 1 inch equals 660 feet, and the 1985 photos are at a scale of 1 inch equals 625 feet.

The differences in scale of each set of aerial photographs made comparison difficult. Only large changes in the stream were observable. Few major changes in the form and location of Maline Creek were noted. Bank erosion was difficult to distinguish on the small scale of the 1964 photographs. Major changes noted include the expansion of Lambert-St. Louis International Airport, the removal of houses near the airport, the construction of the Inner Belt, the construction of Ferguson Road, the extension of Lucas and Hunt Road and associated cutoff of the channel.

In addition to identifying changes along Maline Creek, evaluation was also made of Blackjack Creek. This was done since it is the largest tributary to Maline Creek and significant bank erosion is presently occurring along it. Impacts on Maline Creek due to changes in the amount of sediment being delivered from Blackjack Creek could be potentially significant.

### 4.5.1 Maline Creek Observations

The following is a reach-by-reach description of observations made along Maline Creek from comparison of aerial photographs.

Mississippi River to Riverview Drive

Between 1964 and 1985 this reach showed little change. The channel was found to be in approximately the same position with no noticeable increase in channel width. In 1964 the portion of the reach between the Burlington Northern Railroad bridge and Riverview Drive had recently been channelized. Channel banks were free of vegetation. Successive 1971 and 1985 aerial photographs showed increasing amounts of vegetation on the banks. The 1985 photos show stream banks which are overgrown with trees and bushes.

Riverview Drive to Bellefontaine Road

This reach did not significantly change between 1964, 1971, and 1985 aerial photographs.

Bellefontaine Road to U.S. Highway 67

From 1964 to 1985 this reach showed minor changes. An approximately 500-foot length of the channel in the area immediately downstream of Lewis and Clark Boulevard (U.S. Highway 67) migrated towards the north approximately 20 feet. In the 1985 photos meandering of the stream can be observed. Erosion on the outside of bends and deposition on the inside of bends can be seen.

U.S. Highway 67 to Confluence with Blackjack Creek

In 1964 the stream in this reach can be seen to be meandering. Channel bank erosion was observed and appeared to be endangering a group of houses located to the south of the stream. In 1971 the same reach is seen to have been straightened. No evidence of bank erosion is observable. In 1985 the reach is again showing some signs of meandering. The width of the channel appears to have increased somewhat between the 1971 and 1985 aerial photographs. The increase in stream width and migration of the channel seen in the 1985 photos may be an indication of aggradation of the channel which was noted in the profile comparison presented in Section 4.4.

The tendency of the channel to show signs of migration after being straightened demonstrates that adequate bank protection must be utilized along straightened reaches to prevent a return of a more sinuous condition.

Confluence with Blackjack Creek to Halls Ferry Road

The channel in this reach had not changed significantly between 1964 and 1971. Between 1971 and 1985 bends appear to have become sharper and bank erosion is apparent on the outside of bends. In the 1985 aerial photos, sediment is seen to be depositing at the inside of bends.

Halls Ferry Road to Lucas and Hunt Road

The channel along this reach shows no significant change between 1964 and 1971. Between 1971 and 1985 a meander loop of the channel was cutoff and the channel relocated as part of the construction of Lucas and Hunt Road extension. Approximately 3,600-feet of the natural stream was cutoff, and was replaced with a 1,800 foot channelized reach. The stream in the 1985 photos appears to be more deeply incised than the channel seen in the 1964 or 1971 photographs. The incision of the channel would agree with the degradation observed during field observations.

Lucas and Hunt Road to Glen Owen Drive

The channel in this reach is in the approximate same position between 1967 and 1985 photos upstream of the cutoff. The channel appears more incised in the 1985 photographs. Erosion is apparent along the south bank downstream of the cutoff in the 1985 photos.

Glen Owen Drive to West Florissant Road

No major change in channel location is noted between 1964, 1971, and 1985 photographs. In the 1985 photos, bank erosion is apparent along most of the reach. Channel banks have sloughed in various locations.

West Florissant Road to Ferguson Drive

The channel in this reach has changed significantly between 1964, 1971, and 1985. Successive sets of aerials show increasing bank erosion and stream width. Similarly, the area surrounding the stream shows increasing development in 1971 and 1985 photos. In 1964 and 1971, Ferguson Drive did not cross Maline Creek. In 1971 photos, the area surrounding the stream in the upstream one-half of the reach was undeveloped. Heavy vegetation can be seen. In the 1985 photos, Ferguson Drive was extended across Maline Creek and large portions of the nearby vegetated areas had been developed. Stream banks in the 1985 photos show erosion throughout the reach upstream of Ferguson Branch

(Tributary ME). The channel in the 1985 photos appears wider and a large scour hole is seen at the confluence with Ferguson Branch.

Ferguson Drive to Bermuda Drive

No major changes were noted along this reach between 1964, 1971, and 1985 photographs. Bank erosion in some locations can be seen in the 1985 photographs.

Bermuda Drive to Florissant Road

No significant changes were noted between 1964, 1971, and 1985 photographs. The channel in this reach is fairly straight and is bordered on both banks by residential areas. Bank protection can be seen in the 1985 photos in some locations.

Florissant Road to North Hanley Road

This reach is the most sinuous portion of the stream yet discussed. The channel in the 1971 photos is obscured by vegetation. The channel was seen to be in the same general location in the 1964 and 1985 photos except in one area. Approximately 2,000 feet downstream of North Hanley Road, comparison of 1971 and 1985 photos revealed that the stream had been relocated. An approximately 600-foot long meander bend was cutoff and replaced with a 300-foot channelized section. No significant changes in the channel upstream of the cutoff were noted.

North Hanley Road to I-70

The area between North Hanley Road and I-70 near Maline Creek has changed extensively since 1971. In 1971 the area was residential housing. In 1985 many houses to the north of Maline Creek had been removed because of noise problems associated with Lambert-St. Louis International Airport. Additionally, in 1971 the St. Louis Inner-Belt (I-170) had not yet been constructed. In spite of the major changes which have occurred around it, no significant changes in the channel location were noted between 1971 and 1985 photos. Some bank erosion can be seen in the 1985 photos.

I-70 to Natural Bridge Road

The channel between I-70 and Natural Bridge Road is sinuous. It is in the approximate same location in 1964, 1971 and 1985 photos. Erosion of the channel banks can be seen in the 1985 channel downstream of Natural Bridge Road.

Natural Bridge Road to Inner Belt

The stream in this reach is fairly straight in the 1964 photos. Urban areas confine the channel. In 1985 photos, the Inner Belt Highway had been constructed. The stream follows the highway along its eastern edge. No comparison was made to 1971 conditions as no aerial photographs in this area were available. The channel appears stable in the 1985 photos, it is confined by channelization and closely spaced road crossings.

Inner Belt (I-170) to St. Charles Rock Road

The 1985 aerials show the stream channel and banks to be eroding along this reach. Incised tributaries can be seen along the I-170 roadway embankment.

4.5.2 Blackjack Creek Observations

The following is a reach-by-reach description of observations made along Blackjack Creek from comparison of aerial photographs.

Confluence with Maline Creek to Chambers Road

As seen in the 1971 and 1985 aerial photographs, the channel in this reach is meandering considerably and banks are actively eroding, particularly at the outside of bends. In the 1964 photos the channel appeared to be somewhat more stable. Bank erosion was not as apparent.

Between 1964 and 1971 the channel in the vicinity of the intersection of Halls Ferry Road and Hecht Road can be seen to have migrated to within approximately 30 feet of Halls Ferry Road. In the 1985 photos the bank is approximately 60 feet from the roadway. Reportedly, the channel was moved away from the roadway by filling and placement of bank protection.

In the 1964 and 1971 photos, the portion of the channel located approximately 600 feet downstream of Chambers Road can be seen to be meandering and endangering the Meadows School. In the 1985 photographs, the channel was seen to have been straightened and bank protection installed on the Meadows School side of the channel. The channel in the 1985 photo appears stable.

Chambers Road to Confluence with Dellwood Branch

This reach did not change significantly in location between 1964, 1971, and 1985. The channel is nearly straight. The channel in the 1985 photos appears to be experiencing some bank erosion. Just upstream of the confluence with Dellwood Branch, a sewer line crossing can be seen. During the site visit a drop of approximately 3 feet was seen between the upstream and downstream sides of the crossing.

Confluence with Dellwood Branch to Hudson Drive

Upstream of the confluence this reach of Blackjack Creek is very sinous up to a point approximately half way to Hudson Drive. The channel straightens as it passes through a residential area. No significant changes in channel locations were noted between 1964, 1971, and 1985 photographs. The 1985 channel appears to be experiencing more streambank erosion than could be seen in 1971 or 1964 photographs.

Hudson Drive to Vorhoff Drive

The channel in this reach is in approximately the same location in 1964, 1971, and 1985 photographs. In the 1985 photos bank erosion can be seen in various locations. Additionally, in the 1985 photos approximately 300 feet of bank protection can be seen to have been installed along this reach.

Vorhoff Drive to Confluence with Central City Branch

No significant changes along this reach were observed in comparing 1964, 1971, and 1985 aerial photographs.

Confluence with Central City Branch to I-270

No significant changes along this reach were observed in comparing 1964, 1971, and 1985 aerial photographs.

### 4.5.3 Conclusions

Overall, the Maline Creek channel has not changed location dramatically in the period between 1964 and 1985. Two locations were identified in which the channel had been moved by man's activities. The first location was the cutoff of a meander bend where Lucas and Hunt Road was constructed. The other location was the cutoff of a meander bend downstream of North Hanley Road.

Only the Lucas-Hunt cutoff was noted to have caused significant changes in the channel. Degradation of the channel and increased bank erosion was noted throughout the channel from the downstream end of the cutoff to upstream of Glen Owen Drive.

As seen in the series of aerial photographs, the watershed area has changed only moderately in 21 years. Most of the watershed had already been urbanized in 1964. Development was noticeable in only certain locations. The most prominent changes include Lucas and Hunt Road, Ferguson Road, the Inner Belt (I-170), the expansion of Lambert-St. Louis International Airport, and the removal of houses near the airport.

Overall, the most noticeable change in the Maline Creek channel is an increase in bank erosion. The aerial photographs in 1964 show a somewhat more stable river. Bank sloughs, erosion on the outside of bends, and widening of the channel were noted in many locations in the 1985 photographs.

Blackjack Creek was seen to be very similar to Maline Creek. No major changes in channel location were noted along its length. The 1964 and 1971 photographs showed a more stable stream than that observed in the 1985 photographs. Bank erosion was more evident in 1985.

## 4.6 Comparison of Existing and Proposed Hydraulic Conditions

### 4.6.1 General

To evaluate how the recommended plan will impact sediment transport along Maline Creek, comparison was made of main-channel velocities for existing and proposed hydraulic conditions. The main channel velocity was the only hydraulic parameter compared, since it has the single-greatest effect on sediment transport. The values of main channel velocities were determined from available HEC-II backwater computation models for existing and proposed channel conditions (COE, 1980a).

Comparison of hydraulic variables was made by graphical means. Existing and proposed conditions were plotted and differences between them identified. The velocities for two discharges were compared with 10-year and 100-year return period floods for future development conditions. The 10-year flood was chosen to be compared since it represents a discharge with a small enough return period that it occurs often enough to have a significant impact on the shape and form of the river and yet large enough to effect the entire channel. The 100-year discharge was chosen to be compared since it represents a large event capable of producing sudden, significant changes in the stream.

Figures 4.4 and 4.5 are plots of the main channel velocities determined from HEC-II models for existing and proposed hydraulic conditions along Maline Creek.

4.6.2 10-year Discharge

As can be seen from Figure 4.4, the main-channel velocities for the 10-year discharge and existing hydraulic conditions range between 2 to 20 feet per second (fps). The average range of velocities for the entire stream is 2 to 8 fps. The highest velocities were found at bridges. Four bridges had velocities greater than 8 fps. A list of brigde velocities is presented as Table 4.3.

Main channel velocities for the 10-year discharge and proposed hydraulic conditions were found to be in the same 2 to 20 fps range found for existing conditions. Average velocities for the entire channel were found to be in the range of 2 to 8 fps. Again, the highest velocites were found at bridges. Six bridges were found to have velocities greater than 8 fps.

Comparison of main-channel velocities for existing and proposed hydraulic conditions indicate a general increase in main-channel velocity for proposed conditions of between 1 to 3 fps. As shown on Figure 4.4, in reaches where channel widening and straightening is proposed, main-channel velocity actually decreased from existing conditions. Decreases ranged from 1 to 3 fps. Overall, proposed hydraulic conditions can be expected to increase velocities slightly along the majority of Maline Creek for the 10-year discharge.

Velocities at bridges for existing and proposed conditions vary widely. Five of the bridges listed on Table 4.3 are proposed to be modified as flood control improvements. Bridge modifications did not necessarily decrease velocities. Velocities at bridges increased or decreased according to the condition, such as pressure flow or weir flow at which they were flowing. No general trend was observed as velocities increased at only eight of the 14 bridges modeled.

4.6.3 100-year Discharge

On Figure 4.5 main-channel velocities for the 100-year discharge and existing hydraulic conditions range between 2 to 15 fps. The general range of main channel velocities for existing conditions is between 2 to 8 fps. The highest velocities are found at bridges. Five bridges had velocities greater than 8 fps.

Table 4.3. Bridge Velocities Along Maline Creek.

| Location | 10-year Discharge Existing Hydraulic Condition | 10-year Discharge Proposed Hydraulic Condition | 100-year Discharge Existing Hydraulic Condition | 100-year Discharge Proposed Hydraulic Condition |
|---|---|---|---|---|
| B & N RR | * | * | * | * |
| Riverview Drive | * | * | * | * |
| Bellefontaine Rd** | 2.2 | 3.3 | 2.0 | 2.7 |
| State Highway 367 (Lewis & Clark Blvd) | 3.6 | 3.6 | 3.6 | 3.1 |
| Halls Ferry Road** | 5.3 | 3.8 | 3.8 | 4.1 |
| Lucas and Hunt Road | 5.0 | 8.7 | 4.9 | 7.8 |
| Glen-Woen Drive** | 4.4 | 4.8 | 2.1 | 2.1 |
| West Florissant Rd.** | 7.9 | 6.7 | 11.9 | 6.3 |
| Ferguson Drive | * | * | * | * |
| Wabash RR | 10.3 | 12.3 | 14.3 | 16.3 |
| Bermuda Drive** | 5.0 | 4.3 | 3.4 | 4.5 |
| Wabash RR | 8.4 | 15.1 | 11.6 | 14.6 |
| Florissant Road | 6.8 | 8.2 | 4.4 | 6.4 |
| Martin Luther King Blvd. (Carson Road) | 8.2 | 8.8 | 8.2 | 9.8 |
| I-70 | 7.8 | 7.5 | 10.0 | 9.2 |
| Rolling Drive | 5.6 | 7.0 | 2.4 | 4.8 |
| Natural Bridge Rd | 19.9 | 17.0 | 6.5 | 18.0 |

*Not modeled
**Bridges modified for proposed hydraulic conditions

Main channel velocities for proposed hydraulic conditions range between 2 to 21 fps. The general range of velocities for proposed hydraulic conditions were found to be approximately the same for existing hydraulic conditions, 2 to 8 fps. Comparison of main channel velocities for existing and proposed hydraulic conditions indicate general increase for proposed hydraulic conditions of between 1 and 3 fps. In reaches of proposed channel widening and straightening, channel velocities were found to be between 1 and 3 fps lower than existing conditions. Generally, proposed hydraulic conditions can be expected to increase velocities slightly along most of Maline Creek.

Velocities at bridges vary widely for existing and proposed hydraulic conditions. Velocities increased or decreased according to the flow condition, such as weir flow or pressure flow, of the bridge. Nine of the 14 bridges demonstrated an increase in velocity.

### 4.6.4 Impact of Velocity Differences

#### 4.6.4.1 Channel Profile

The impact of the overall slight velocity increase of 1 to 3 fps observed for the 10-year and 100-year discharges and proposed improvement conditions on sediment transport along Maline Creek is expected to be minimal. The degradation of the channel profile illustrated in Section 4.4 indicates an existing deficit of available sediment to transport capacity in the stream. Slightly increasing the transport capacity of the stream will only marginally affect a situation that is already out of balance.

Other reasons also exist as to why the increase in velocity is insignificant relative to sediment transport. First, over most of its length the channel is now incised into a stiff, erosion resistant clay material that is much more erosion resistant than the fine loess material found in the banks. Second, the numerous concrete encased sewer line crossings of the stream are presently acting as grade controls for the stream. They will continue to do so, as long as they are maintained, and will effectively control the channel profile. Finally, the numerous aquatic habitat structures proposed for the stream will also act to control the profile of the channel.

The increase in velocity may also cause the sediment depositing near the confluence with Blackjack Creek to be eroded away. This change in base level for Blackjack Creek could cause degradation of its profile. A grade control structure on Blackjack Creek may be required as stabilization.

4.6.4.2 Bank Erosion

Observations made during the site visit indicate that bank erosion is already a problem along most of Maline Creek. The sediment transport capacity of the existing channel is thought to be much greater than available sediment supply. Any unprotected or unvegetated bank exposed to the flow is subject to erosion. An increase in velocity of 1 to 3 fps associated with proposed hydraulic conditions will not significantly increase bank erosion.

It was concluded from site visit observations that occurrences of bank erosion are caused as much by the geotechnical properties of the soil as by hydraulic conditions. Wherever a failure of a slope or existing bank protection measures was caused by geotechnical considerations of the soil, the bank is subject to bank erosion. The prevention of drainage flowing over banks and proper engineering of bank protection measures is expected to have the greatest positive effect on bank erosion along the creek.

4.6.4.3 Bridges

Sediment transport at bridges can be expected to vary dramatically for the various flow conditions expected at each bridge. Generally, the flow at bridges is confined enough to cause large velocities. Adequate protection of banks along transitions into and out of bridges and proper consideration of local scour depth must be made.

## 4.7 Effect of Recommended Improvements on Sediment Transport and Erosion

Evaluation of how channel improvements associated with the recommended plan will effect sediment transport and erosion along Maline Creek was made based on information about each improvement contained in the 1980 survey report (COE). Proposed improvements which would potentially effect the hydraulics of the stream include detention basins, channel modifications, low-level levees, and floodwalls, channel clearing, bridge replacements and modifications, and aquatic habitat structures.

In the following sections, discussion of each proposed improvement and its potential effect on sediment transport and erosion along the stream is made. Additionally, where undesirable impacts on sediment transport and erosion are anticipated to be caused by the proposed improvement, means of negating or mitigating such impacts are proposed.

4.7.1 Detention Basins

Eight sites are identified in the recommended plan to provide storm water detention. The eight sites proposed are shown on Figure 4.6. Data for each site is listed in Table 4.4.

As can be seen in Figure 4.6, the only one of the eight proposed detention basins (M27) is to be located on the Maline Creek mainstem. It is located near the upstream end of Maline Creek. It controls a drainage area of 525 acres or 3.2 percent of the entire watershed.

The seven proposed detention sites are located along tributaries to Maline Creek. Three of the seven are to be located on the largest tributary to Maline Creek, Blackjack Creek (MD-1). Two of the three are located on the tributaries to Blackjack Creek, one on Dellwood Creek and on Central City Branch.

The effect of proposed detention basins on sediment transport along Maline Creek is expected to be minimal for several reasons. First, the area which the detention basins control is only 14.3 percent of the watershed. The remaining 85 percent of the watershed is still free to contribute sediment even assuming a 100 percent trap efficiency for the detention sites. Secondly, the overall degradation of the channel profile shown in Section 4.4 indicates an existing overall deficit in the available supply of sediment compared to transport capacity. A fractional decrease in sediment supply caused by construction of the detention basins will only slightly aggravate an existing situation. Thirdly, degradation of the channel is already being controlled to some degree by the erosion resistant clayey loess in which the channel has incised over much of its length, the numerous existing pipeline crosssings of the stream, and the large amounts of rubble that are now in the bed. Finally, the 18 aquatic habitat structures proposed to be constructed along the stream are expected to act as grade control/drop structures, further stabilizing the channel profile.

4.7.2 Channel Widening and Straightening

4.7.2.1 General

Portions of Maline Creek, Moline Acres Creek, (MC), and Blackjack Creek (MD) are identified in the recommended plan to be widened and straightened. Proposed channel designs include a concrete U-shaped channel, a trapezoidal concrete channel and a trapezoidal earth channel. Typical sections for each design are presented as Figure 4.7.

Table 4.4. Detention Basin Data.

| Site | Stream | Percentage of Total Watershed | Maximum Pool Area (Acres) | (Acre/Feet) |
|---|---|---|---|---|
| M27 | Maline Creek | 3.2 | 63 | 942 |
| M22 | Unnamed Tributary to Maline Creek | 0.6 | 16 | 215 |
| MH1 | Kinlock Branch | 0.8 | 20 | 277 |
| MF1 | Ball Creek | 1.9 | 30 | 514 |
| MF2 | BAll Creek | 1.4 | 6 | 56 |
| MD1 | Blackjack Creek | 2.6 | 10 | 52 |
| MD2-2 | Central City Branch | 1.2 | 30 | 407 |
| MD1-1 | Dellwood Creek | 2.6 | 52 | 786 |

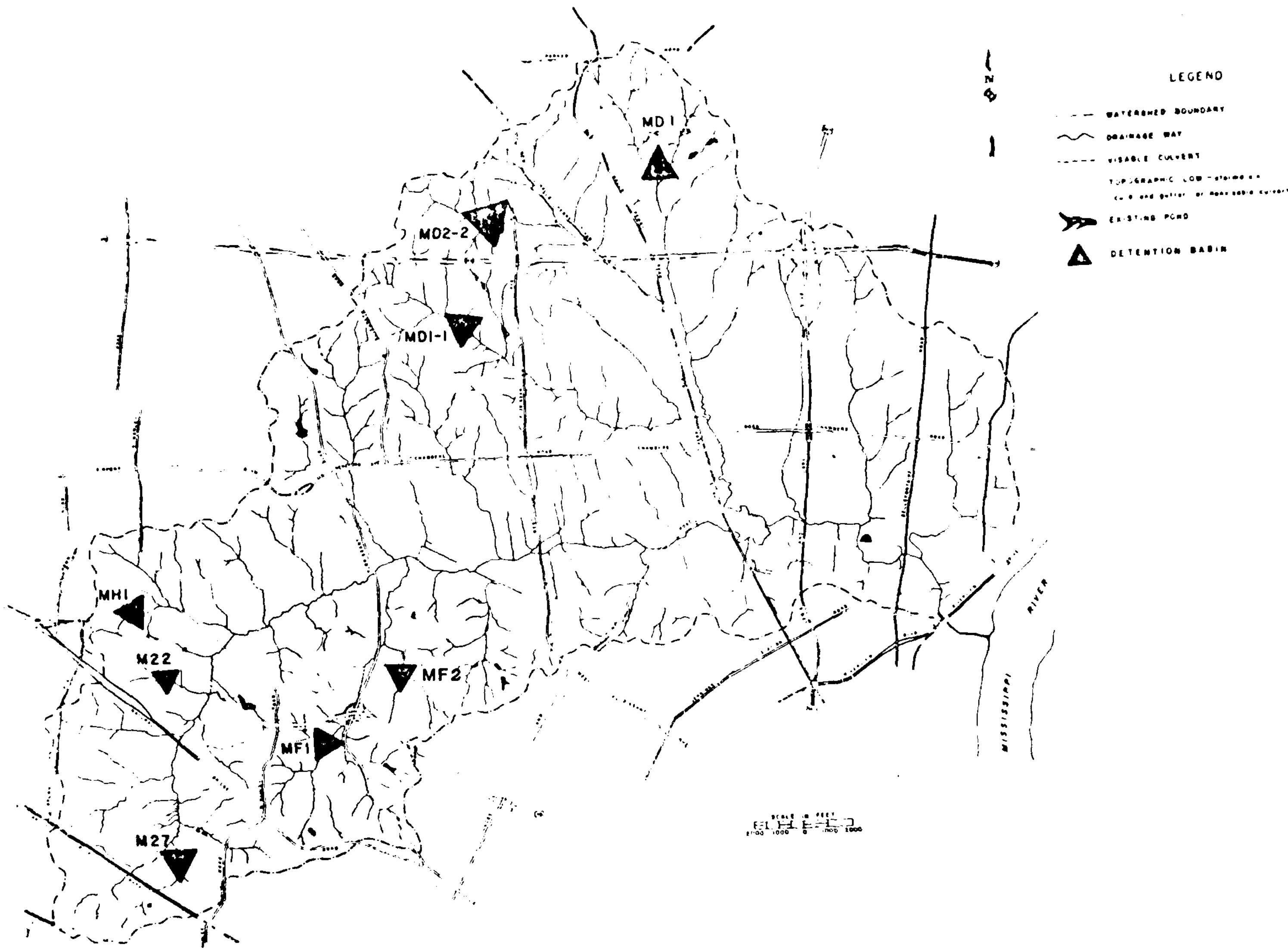
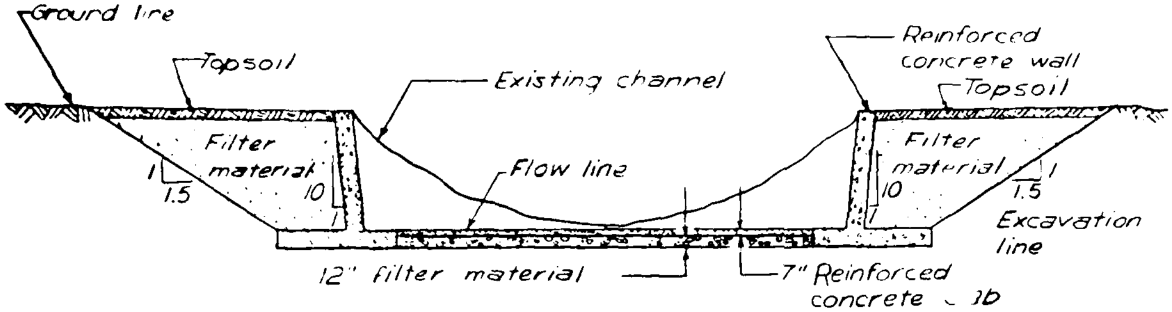
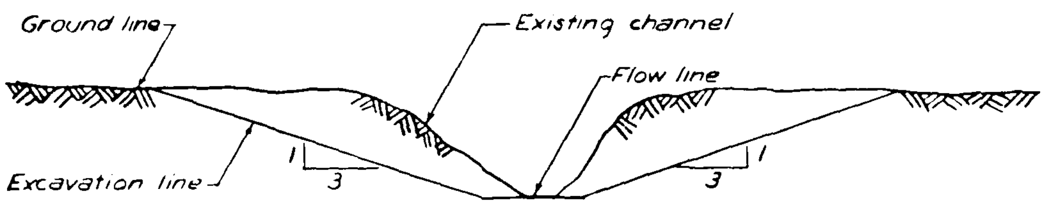



Figure 4.6. Proposed detention basins in the Maline Creek watershed.



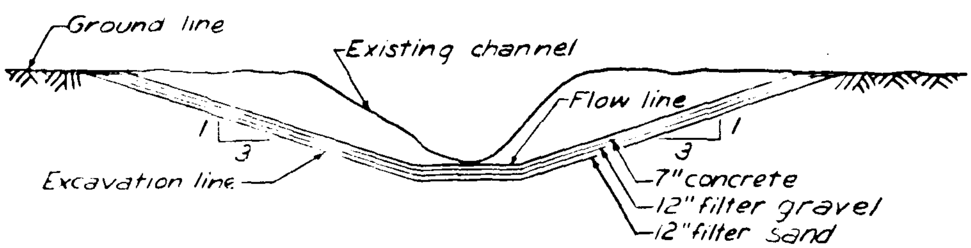

## U-SHAPED CONCRETE CHANNEL

NO SCALE




## TRAPEZOIDAL EARTH CHANNEL

NO SCALE




## TRAPEZOIDAL CONCRETE CHANNEL

NO SCALE

Figure 4.7. Typical sections of proposed channel modifications.

As was demonstrated in the comparison of hydraulic conditions for existing and proposed conditions of the channel the increase or decrease in velocity caused by recommended improvements will generally not affect sediment transport in Maline Creek. It was also shown that at each of the locations where widening and straightening of the channel was proposed, the main channel velocity actually decreased between 1 and 3 fps for the 10- and 100-year discharges. This slight decrease in channel velocity is not expected to cause sedimentation problems since their is an existing deficit of available sediment compared to the transport capacity of the stream.

The comparison of aerial photographs previously presented showed that sections of Maline Creek which had been straightened have a tendency to return to a meandering pattern. This tendency was also observed during the site visit in the channelized reach upstream of Glen Owen Drive. To prevent this it will be necessary to provide adequate protection of banks along reaches utilizing the trapezoidal earth channel design.

4.7.2.2 Design and Construction Considerations

Review of designs proposed for channel modifications was made to assess their effect on sediment transport.

4.7.2.2.1 Concrete lined U-shaped and Trapezoidal Channels. The fine loess material on to which the concrete channel is to be placed will require special considerations to prevent foundation problems. Adequate filters should be used to prevent leaching of material from underneath channel sections and from joints in the channel.

From discussions with the Metropolitan St. Louis Sewer District (MSD) it was learned that in the past they had experienced problems with 2 horizontal to 1 vertical sideslope trapezoidal concrete-lined channels. A common condition was described where the sideslope failed approximately one-third of the distance up the sideslope allowing foundation material to wash out. Figure 4.8 is definition sketch of the problem. MSD said that failures occurred even though adequate weep holes and filters were utilized. They also said that modification of the standard design used for concrete trapezoidal channels seemed to have prevented this problem from occurring. The modification changed using a 4-inch thick wire mesh reinforced sidewall to a 7-inch thick steel reinforced sidewall.

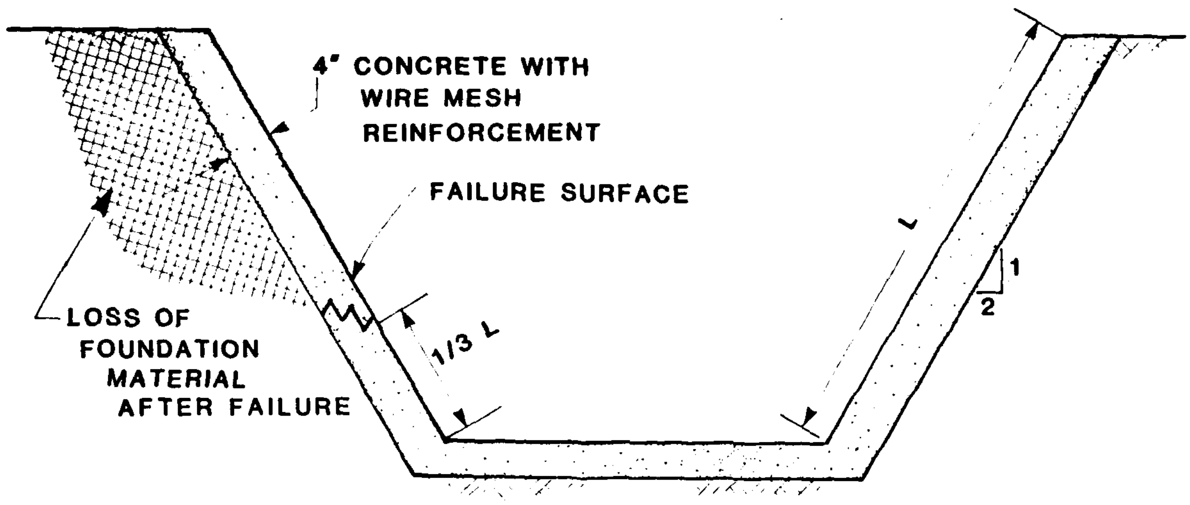



Figure 4.8. Typical failure of concrete trapezoidal channel as described by Metropolitan St. Louis Sewer District.

One possible explanation for the slope failure problem is that loess becomes saturated soil behind the sidewall and exerts enough pressure to cause failure. Weep holes and filters present in the sidewalls cannot adequately drain the loess because of its low permeability. The modified 7-inch steel reinforced sideslope is apparantly strong enough to prevent saturation of material used as foundation for the sideslopes.

4.7.2.2.2 Trapezoidal Earth Channels. One conclusion drawn from site visit observations is that one of the main reasons for bank erosion along Maline Creek is stability problems associated with the geotechnical characteristics of the fine loess material found in the watershed. Constructing a stable channel in the loess material will require that proper consideration be given to geotechnical characteristics of the soil. Design of the channel should consider the stability of the 3:1 sideslopes for various densities and levels of saturation. Excavation and recompaction of sideslopes to achieve the required density may be required. Similarly, the diversion or proper channelization of drainage that might flow over the banks of the channel should be considered to prevent localized erosion and saturation of the channel sideslope.

Another observation made during the site visit which is applicable to the proper construction of a stable earth channel is that bank erosion occurred wherever adequate vegetative or man-made protection was absent. Proper consideration should be given to re-establishment of vegetative cover. Scheduling of construction should be made so that grasses can be well established along banks prior to the time of year when the stream is most likely to experience flood flows, May through August. Where establishment of vegetative cover is not possible man-made bank protection such as riprap bedded on filter cloth should be considered.

4.7.3 Low-level Levees and Floodwalls

Low-level flood protection is proposed along portions of Maline Creek, Blackjack Creek, Dellwood Creek, and Kinlock Creek. General designs for the structures are presented on Figure 4.9.

The comparison of existing and proposed hydraulic conditions along Maline Creek did not reveal any significant change in main channel velocities caused by the low-level flood protection. This is probably due to the fact that the

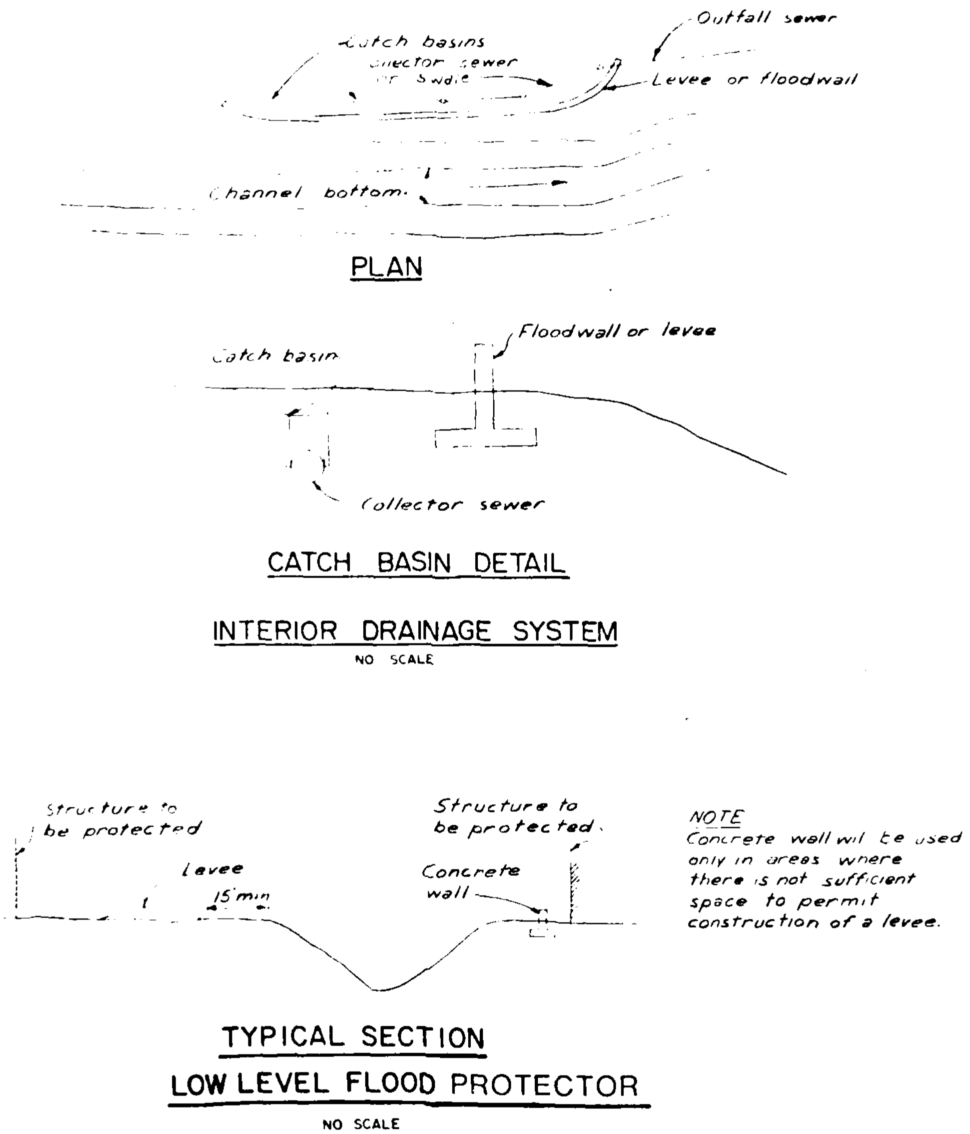



Figure 4.9. Typical designs for low-level flood protectors.

structures are to be set back from the main channel, thus minimizing their effect. Additionally, the low-level flood protectors will only effect flows greater than bankfull and less than approximately the 10-year discharge.

An important consideration in the design of the low-level flood protection is adequate provision for drainage of runoff that will collect behind each structure. Saturation of the fine loess material on which the protection is to be founded should be prevented to avoid geotechnical failures of stream banks and consequent erosion. It is believed the saturation of the fine loess could cause a failure surface to develop through the stream bank.

### 4.7.4 Channel Clearing

Ninety-one acres of channel clearing is proposed in the recommended plan. The removal of vegetation and debris will decrease the roughness of the channel resulting in higher main-channel velocities. Increases in velocity, in the range of 1 to 3 fps, are not expected to significantly increase erosion along the creek. This is due to the erosion resistant clay into which the channel is incised, the numerous pipeline crossings which stabilize the channel and the 18 proposed aquatic habitat structures which are expected to act as grade controls.

The removal of vegetation could potentially expose presently stable streambanks to erosion. Clearing of channels should be scheduled after the potential flood season of May to August, so that grasses can be re-established along banks prior to the next flood season. Additionally, debris generated by vegetation removal should be disposed of properly. If left in the channel, debris could hang up along banks or bridge piers causing increased local scour.

### 4.7.5 Bridge Replacements

The 1980 survey report recommended that five bridges along Maline Creek be replaced as flood improvements. To identify whether any of the bridges are currently planned to be replaced, the Missouri State Highway Department and St. Louis County Highway Department were contacted. It was found that only the Bellfontaine Road bridge is currently scheduled for replacement along Maline Creek. Florissant Road bridge is planned for replacement but not until approximately 1990. No designs for its replacement have been made.

It was pointed out during conversations with the various highway departments that even if the various bridges proposed to be replaced were, their basic dimensions would probably be very similar to what they are now. This is because of the many constraints on the design which exist pertaining to existing roadway grades, elevations of nearby structures and transportation requirements. Because of this, it can be concluded that the existing bridge hydraulics are fairly characteristic of those associated with future bridge replacements.

From the comparison of existing hydraulics presented in Section 4.6 it can be seen that velocities through bridges range between 2 to 20 fps. Velocities are highly dependent on the flow condition, such as pressure flow or weir flow, of the bridge. Generally, all the bridges along Maline Creek may be subject to velocities in excess of 8 fps. In view of the fairly high velocities found at bridges, the critical aspects of bridge design related to sediment transport include proper orientation of piers and pier walls to the flow, making smooth channel transitions into and out of the bridge, proper engineering of bank protection along transitions and at abutments and adequate consideration of potential local scour.

### 4.7.6 Aquatic Habitat Structures

In an effort to provide better habitat for aquatic species along Maline Creek a series of 18 aquatic habitat structures as seen in Figure 4.10 are proposed to be constructed. The structures are to be located in the main channel of the stream and are to be constructed of rock-filled gabions. The structures are expected to act as grade controls to prevent degradation. The overall effect is expected to improve the aquatic habitat because the current trend of the creek is degradation. In the area near the confluence of Blackjack Creek and Maline Creek it was seen in the profile comparison that Maline Creek is aggrading. In this area it is not recommended that the aquatic habit structures be constructed. The structures would only aggravate the sedimentation occurring in this area and would probably be buried by sediment negating their purpose.

The overall velocity increase of 1 to 3 fps determined in Section 4.4 for Maline Creek may cause the sediment deposited near the confluence with Blackjack Creek to be eroded away. If this occurs, it may cause a lowering of the base level for Blackjack Creek and increased channel instability such as degradation of the channel profile. In such an event, construction of one or more aquatic habitat/drop structures along the lower portion of Blackjack Creek to prevent profile degradation may be desirable.

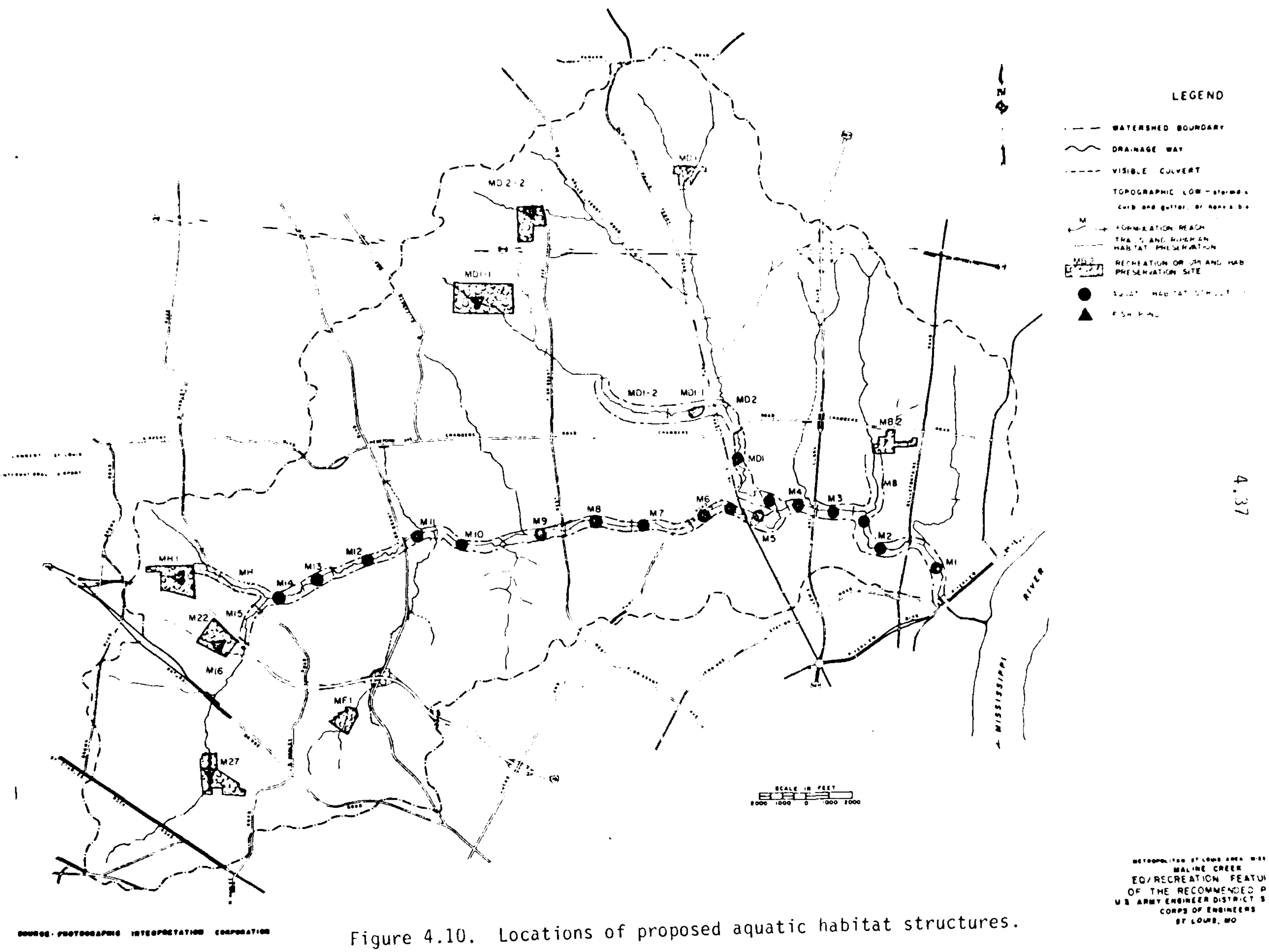



Figure 4.10. Locations of proposed aquatic habitat structures.

A review was made of the proposed design for the aquatic habitat structures to determine its potential effect on sediment transport. As seen in Figure 4.11 no bank protection is utilized on the sideslopes of the channel. It is recommended that proper bank protection be provided since the banks are composed of fine loess material, which is highly erodible. Without proper bank protection it is possible that the stream could bypass the structure.

Another recommendation for their design is to toedown the structure at least 3 feet on the downstream side. The purpose of the toedown is to prevent headcutting of the channel underneath the structure.

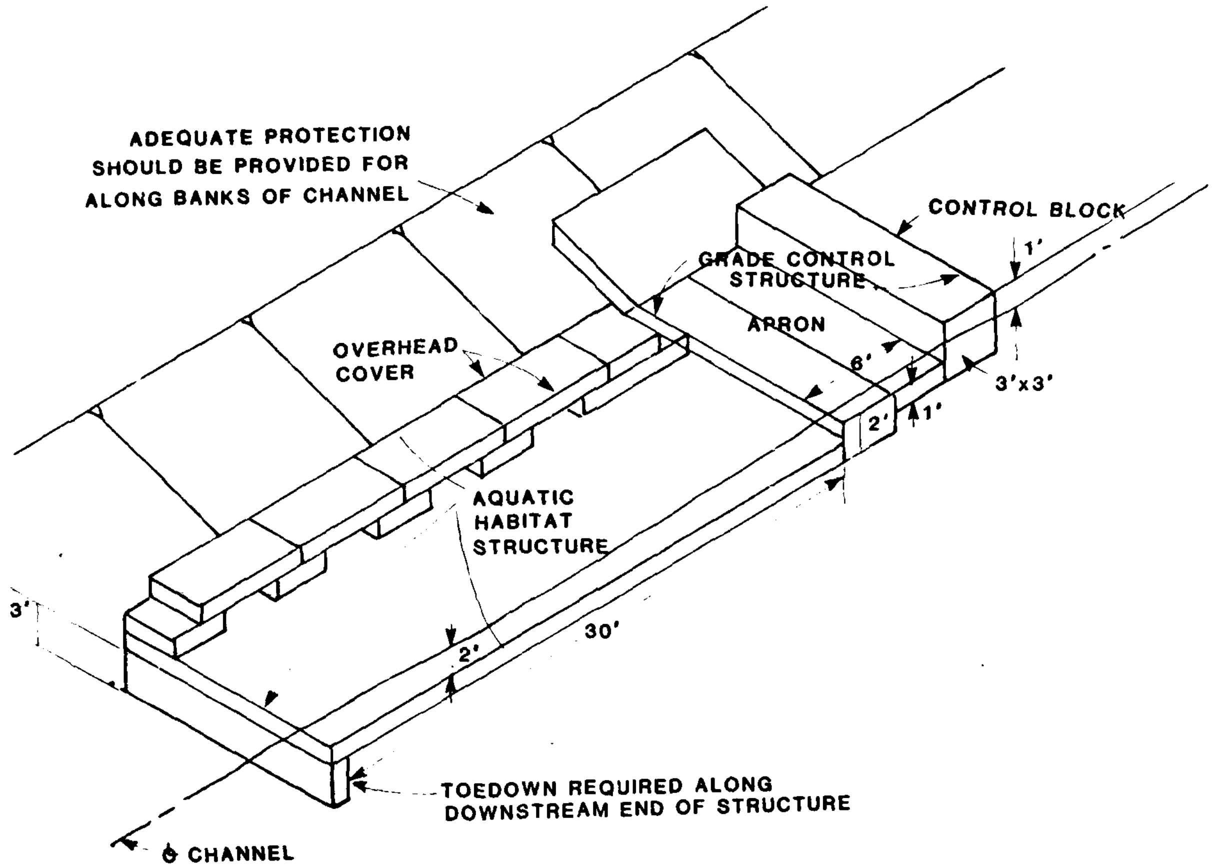



Figure 4.11. COMBINATION AQUATIC HABITAT AND GRADE CONTROL STRUCTURE

# V. SUMMARY AND CONCLUSIONS

In the previous chapters a qualitative evaluation of sediment transport along Maline Creek was made to evaluate potential impacts of impr ements recommended for the stream. Additionally, recommendations were made for mitigating potential negative impacts.

Based on the analysis presented in the previous apters, the following conclusions and recommendations are summarized. As described in the 1980 Survey Report, Maline Creek is presently nothing more than an "urban storm sewer". It is controlled to a large degree by the e nsive amount of urban area in the watershed. In the last 21 years only two major shifts in the location of the Maline Creek have occurred. One downstream of North Hanley Road, the other at Lucas and Hunt Road. Both were the result of channel relocation. The large number of bridges, numerous structures bordering the stream and extensive bank protection measures found along the stream make major changes in channel location unlikely.

The channel bed profile was shown to have degraded between 1 to 3 feet over most of its length. The only aggradation noted was at the confluence with Blackjack Creek. The degradation of the channel was attributed to an existing deficit of available sediment compared to the transport capacity of the stream. The deficit is the result of an increase in runoff and decrease in available sediment supply caused by increasing urbanization. It is believed, however, that degradation of the channel will not continue as rapidly as experienced in the past. Erosion of the channel bed is expect to be controlled for several reasons, the erosion-resistant clayey loess layer in which the channel is now incised, the large amount of rubble from bank protection which is armoring the bed, and the numerous pipeline crossings of the stream which are acting as grade controls.

The geotechnical characteristics of the fine loess material found in streambanks is thought to control bank erosion as much as hydraulic conditions. Many observations were made during the site visit of bank erosion problems where saturation of bank material was the likely the cause of bank failure.

Comparison of main channel velocities for existing and proposed hydraulic conditions of Maline Creek indicate that a general increase in velocity of between 1 to 3 fps can be expected for 10-year and 100-year discharges. Velocities are expected to decrease from existing conditions, 1 to 3 fps in reaches where channel widening and straightening is proposed.

The effect of the general increase in velocity on sediment transport along Maline Creek is expected to be insignificant. Reasons for this include the erosion-resistant clayey loess in which the channel is incised, the extensive amounts of rubble from bank protection which practically armor the channel bed, the numerous existing pipeline crossings of the stream acting as grade controls and the 18 proposed aquatic habitat structures which are expected to act as grade controls.

No unavoidable significant impacts on sediment transport along Maline Creek are expected to be caused by the channel improvements included in the recommended plan.

Adverse impacts on property adjacent to the stream can be avoided by proper utilization of bank protection, either vegetative or structural.

Recommendations made to modify improvement designs to avoid potential impacts include the following:

1. Channel Widening and Straightening

   a. <u>Concrete-lined Channels</u>

   Special consideration must be given to the geotechnical properties of the fine-grained loess foundation material. Adequate filters must be utilized at weep holes and joints to prevent leaching of foundation material. Forces on sideslopes must also be analyzed to consider saturated foundation material, or special provision must be mad to prevent saturation of material along sideslopes.

   b. <u>Earth Channels</u>

   Special consideration must be given to the geotechnical properties of the fine-grained loe^s material in which the channel is to be constructed. Analysis should be made of the 3:1 sideslopes recommended and their stability for various levels of soil densification and saturation.

   Diversion or controlled collection and disposal of local drainage which might flow over channel banks is recommended to prevent local erosion and saturation of sideslopes.

   Proper consideration must be made of re-establishment of vegetative cover to prevent erosion. Scheduling of construction should be made so that grasses will be well established prior to the potential flood season, May through August.

   Site visit observations and analysis of aerial photographs revealed that sections of Maline Creek which have been straightened have a tendency to return to a meandering pattern. To prevent this, it will be necessary to provide adequate protection of banks along reaches utilizing the trapezoidal earth design. Riprap bedded on filter cloth and other man-made protection should be considered as potential forms of bank protection.

2. Low-level Flood Protectors

Adequate provision must be made for drainage of runoff that collects behind levees and floodwalls. This will help prevent saturation of streambanks and potential failures of channel sideslopes.

3. Channel Clearing

Clearing of channels should be scheduled so that any disturbance of grasses that prevent erosion can be re-established prior to the potential flood season, May through August. Debris generated by the clearing must also be properly disposed of to prevent collection of debris along channel banks and on bridge piers. Debris could potentially cause blockage of bridge spans and undesirable local scour problems.

4. Bridge Replacements

Any bridge replacement designs should ensure that piers and pier walls be properly aligned with the flow in the channel, that transitions into and out of bridges are smooth, bank protection along transitions and abutments is properly engineered and adequate consideration be given to potential scour depths relative to footing elevations.

5. Aquatic Habitat Structures

Adequate protection must be utilized to control erosion on channel sideslopes in view of the hydraulic disturbance that will be caused by the structures. Without proper protection, the highly erodible fine-grained loess material found in the banks will be eroded and potentially the channel could bypass the structure.

Another recommendation is that adequate toedown be provided along the downstream edge of the structure. Since the Maline Creek profile is seen to be degrading adequate toedown, estimated to be 3 feet, should be provided to prevent undercutting of the structure.

In the vicinity of the confluence with Blackjack Creek, the Maline Creek channel has been aggrading. It is not recommended that structures be located in this area. The slight overall increase in channel velocity associated with proposed channel improvement may cause the aggradation to stop and possibly erode away deposited material. If this occurs it could cause a lowering of the base level for Blackjack Creek. This may initiate erosion of the channel bed along Blackjack Creek. In such an event, it may be necessary to stabilize Blackjack Creek with one or more drop structures such as the aquatic habitat structures.

## VI. REFERENCES


1. Computer Search of Water Resources Abstracts Database Using DIALOG Information Retrieval Service.

2. Computer Search Utilizing Online Access Catalog of Colorado Alliance of Research Libraries.

3. Corps of Engineers, Water Resources Investigation St. Louis Metropolitan Area Missouri and Illinois, Maline Creek, Missouri. Survey Report Department of the Army, St. Louis District, St. Louis, Missouri, 1980.

4. Lutzen, E.J. and John Rockaway, Jr. Engineering Geology of St. Louis County, Missouri Mo. Geol. Surv. and Nat. Res. Eng. Geol. Ser. 4, 1971.

5. Metropolitan St. Louis Sewer District, Maline Creek Storm Water Study MO. P-2G Comprehensive Stormwater Planning Program to Determine Alignment and With of Floodway Reservations, 1964.

6. Soil Conservation Service, Aerial Photographs of Maline Creek Watershed, Scale 1" = 660', 1971.

7. St. Louis District, Corps of Engineers, Aerial Photographs of Maline Creek Watershed, Scale 1" = 2,000', 1964.

8. St. Louis District Corps of Engineers, HEC-2 Water Surface Computation Model Data, Used in 1980 Survey Report, 1980a.

9. St. Louis District Corps of Engineers, Aerial Photographs of Maline Creek Watershed, Scale 1" = 625', 1985.

10. St. Louis District, Corps of Engineers, Channel Bed Elevation Survey, 1985.

11. United States Department of Agriculture, Soil Conservation Service in cooperation with Missouri Agriculture Experiment Station, Soil Survey of St. Louis County and St. Louis City, Missouri. April 1982.

12. Water Resources Investigation, St. Louis Metropolitan Area Missouri and Illinois, Maline Creek, Missouri Survey Report, Department of the Army, St. Louis District Corps of Engineers St. Louis Missouri, Volumes I, II, III, September 1980.

APPENDIX A

BIBLIOGRAPHY

OF

LITERATURE REVIEW

Alberts, E.E., G.E. Schuman, and R.E. Barwell, 1978. Seasonal Runoff Losses of Nitrogen and Phosphorus from Missouri Valley Loess Watersheds. J. Environmental Quality Vol. 7. p. 203-208.

Alberts, E.E., R.C. Wendt, R.F. Piest, 1983. Physical and Chemical Properties of Eroded Soil Aggregates Transact. American Society Agriculture Engineering. Vol. 26, p. 465-471.

Alley, W., 1974. Effects of Stormwater Detention in Urban Areas, Urban Drainage and Flood Control District of Denver, Denver, Colorado.

American Public Works Association, 1969. Water Pollution Aspects of Urban Runoff, Federal Water Pollution Control Administration, U.S. Department of the Interior.

Benner, R.E., 1985. Urban Sediment and Stormwater Control: The Maryland Experience. J. Soil and Water Conservation Vol. 40, p. 72-75.

Berg, L., 1964. Loess as a Product of Weathering and Soil Formation. Jerusalem, Israel Program for Scientific Translations, Office of Technical Services, U.S. Dept. of Commerce, Washington, D.C. p. 207.

Boesch, B.E., C.A. Eacker, 1972. Urban erosion -- practical alternatives. University of Kentucky, Technical Report UKY 51-72-CE16, p. 96-107.

Bradford, J.M., D.A. Farrell, W.E. Larson, 1973. Mathematical Evaluation of Factors Affecting Gully Stability. Soil Science Society of America Proceedings, Vol. 37, No. 1, p. 103-107.

Bradford, J.M. and R.F. Piest, 1981. Erosional Development of Valley-bottom Gullies in the Upper Midwestern United States, in D.R. Coates and J.D. Vited (ed.). Thresholds in Geomorphology. George Allen and Unwin, London p. 75-101.

Brandsetter, A., R.L. Engel, and D.B. Cearlock, 1973. "A Mathematical Model for Optimum Design and Control of Metropolitan Wastewater Management Systems," Water Resources Bulletin, Vol. 9(6), December, pp. 1188-1200.

Brandsetter, A., 1976. Assessment of Mathematical Models for Storm and Combined Sewer Management, prepared for Municipal Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency.

Crawford, N.H., 1971. Studies in the Application of Digital Simulation to Urban Hydrology, Hydrology International, Inc., Palo Alto, California, prepared for Office of Water Resources Research.

Crawford, N.H., 1973. Computer Simulation for Design Criteria for Urban Flow Systems, Hydrocomp International, Inc., Palo Alto, California, prepared for Office of Water Resources Research.

Dallaire, G., 1976. Controlling Erosion and Sedimentation at Construction Sites. Civil Engineering, p. 73-77.

Daniels, R.B., R.G. Jordan, 1966. Physiographic History and the Soils, Entrenched Stream Systems and Gullies, Harrison County, Iowa. USDA Tech. Bull. 1348.

De Tar, W.R., J.J. Ross and R.L. Cunningham, 1980. Estimating the C factor in the universal soil loss equation for landscaped slopes. J. Soil and Water Conservation. Vol. 35, p. 42-44.

Ferguson, B., 1978. Erosion and Sedimentation Control In-site Master Planning. J. Soil and Water Conservation p. 167-172.

Frye, J.C., 1947. The Late Pleistocene Loesses of Central Kansas. State Geological Survey of Kansas, Bulletin 70, pt.3.

Grover, P., 1983. Mathematical Modeling of Water and Sediment Yields from Complex Urban Drainage Basins. Colorado State University, Master Thesis. Fort Collins, Colorado.

Guy, H.P., 1974. An Overview of Urban Sedimentology. Kentucky University, Office of Research and Engineering Services, UKY BU106, p. 149-159.

Guy, H.P., 1970. Sediment Problems in Urban Areas. U.S. Geological Survey, Circular 601-E, 8 p.

Harrington, W., A.J. Krupnick, H.M. Peskin, 1985. Policies for Nonpoint Source Water Pollution Control. J. Soil and Water Conservation. Vol. 40, p. 27-32.

Heineman, H.G., D.L. Rausch, 1976. Distribution of Reservoir Sediment--Iowa and Missouri Deep Loess Hills. Proceedings of the Third Federal Inter-Agency Sedimentation Conference, Water Resources Council, Washington, D.C., Sedimentation Committee, p. 4-138--4-148.

International Symposium on Urban Hydrology, 1983. Proceedings of the International Symposium on Urban Hydrology (Urban Hydrology Committee of the American Geophysical Union and the Urban Water Resources Research Council of the American Society of Civil Engineers). American Geophysical Union. Baltimore, Maryland, May 30-June 2, 1983.

Kanerva, R.A., M.A. Ports, 1976. Urban Sediment Control: The Maryland Experience, In Soil Erosion: Prediction and Control. Soc. J. Soil & Water Conservation.

Keren, R., I. Shainberg, H. Frenkel, Y. Kalo, 1983. The Effects of Exchangeable Sodium and Gypsum on Surface Runoff from Loess Soil. Soil Sci. Sco. Am. J., Vol. 47, p. 1001-1004.

Krinitzsky, E.L., 1967. Loess Deposits of Mississippi. Geological Society of America, p. 64.

Kuo, C.Y., 1976. Evaluation of Sediment Yields Due to Urban Development National Technical Information Service, Springfield, VA. PB-267 212, Virginia Water Resources Research Center, Blacksburg, Bulletin 98.

Lohnes, R.A., R.L. Handy, 1968. Slope angles in Friable Loess. J. Geol (76) p. 247-258.

Lowery, B., G.F. Kling, J.A. Vomocil, 1982. Overland Flow From Sloping Land: Effects of Perched Water Tables and Subsurface Drains. Soil Sci. Sco. Am. J., Vol. 46.

Lutzen, J., and John Rockaway, Jr., 1971. Engineering Geology of St. Louis County, Missouri, MO Geol. Surv. and Nat. Res. Eng. Geol. Ser. 4.

Mertes, J.D., 1984. Erosion Prevention Strategies - Review of Current Practices and Prevention Strategies. In Proc. of Conference XV, International Erosion Control Associates, p. 51-62.

Mevius, F., 1973. Analysis of Urban Sewer Systems by Hydrograph-Volume Method, paper presented at the National Conference on Urban Engineering Terrain Problems, Montreal, Quebec, Canada.

Meyer, L.D., 1974. Overview of the Urban Erosion and Sedimentation Processes in National Symposium on Urban Rainfall and Runoff and Sediment Control. University of Kentucky BU106, p. 15-23.

Mucher, H.J., J. De Ploey, 1977. Experimental and Micromorphological Investigation of Erosion and Redeposition of Loess by Water Earth Surface Processes, Vol. 2, p. 117-124.

Myers, C.F., J. Meck, S. Tuller, A. Weinberg, 1985. Nonpoint Sources of Water Pollution. J. Soil and Water Conservation (40), p. 14-22.

Piest, R.F, C.E. Beer, R.G. Spomer, 1976. Entrenchment of Drainage Systems in Western Iowa and Northwestern Missouri. Water Resources Council, Washington, D.C., Sedimentation Committee, p. 5-48--5-60.

Piest, R.F. S. Ziemnicki, 1977. Comparative Erodibility of Loess Soils in Poland and the United States. Agr. Research Service, Columbia, MO, Soc. Agr. Eng., Dec 13-16, 1977. Chicago, IL p. 29.

Piest, R.F., S. Ziemnicki, 1979. Comparative Erosion Rates of Loess Soils in Poland and Iowa. Transactions of the American Society of Agricultural Engineers, Vol. 22, No. 4, p. 822-827.

Ports, M.A., 1973. Urban Sediment Control Design Criteria and Procedures. Paper 75-2567. Am. Soc. Agr. Eng., St. Joseph, Michigan.

Powell, M.D., W.C. Winter, W.P. Bodwitch, 1970. Urban Soil Erosion and Sediment Control. NTIS, PB-196 111. Water Pollution Control Research Series 15030 DTL.

Roloff, G., J.M. Bradford, C.L. Scrivner, 1981. Gully Development in the Deep Loess Hills Region of Central Missouri. Soil Science Society of America, Vol. 45, No. 1, p. 119-123.

Ross, J.J., W.R. DeTar, R.L. Cunningham, 1980. Estimating the C Factor in the Universal Soil Loss Equation for Landscaped Slopes: A Field Rating System. Journal of Soil and Water Conservation, Vol. 35, No. 1, p. 40-41.

Saxton, K.E., R.G. Spomer, L.A. Kramer, 1971. Hydrology and Erosion of Loessial Watersheds. ASCE Proceedings, of the Hydraulics Division, Vol. 97, No. HY 11, Paper 8523, p. 1835-1851.

Skaggs, A.W., A. Nassehzadeh-Tabrizi, G.R. Foster, 1982. Subsurface Drainage Effects on Erosion. J. Soil and Water Conservation.

Sheeler, J.B., 1968. Summarization and Comparison of Engineering Properties of Loess in the United States, In Conference on Loess: Design and Construction. Highway Res. Board Vol. 212, p. 1-9.

Simons, D.B., R.M. Li, and M.A. Stevens, 1975. Development of Models for Predicting Water and Sediment Routing and Yield from Storms on Small Watersheds, prepared for USDA Forest Service, Rocky Mountain Forest and Range Experiment Station.

Simons, D.B., R.M. Li, W.T. Fullerton, T.R. Grindeland, 1981. Storm Water and Sediment Runoff Simulation for a System of Multiple Watersheds Volume II: Sediment Routing and Yield, prepared for the USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.

Simons, Li & Associates, Inc. 1983. Design of Sediment Control Measures for Small Areas in Surface Coal Mining for Office of Surface Mining. No. J5110061.

Soils Conservation Service, 1975. Erosion and Sediment Control Handbook For Urbank Areas. Morgantown, West Virginia,

Soil Survey of St. Louis County and St. Louis City, Missouri, United State Department of Agriculture, Soil Conservation Service in cooperation with Missouri Agricultural Experiment Station, April 1982.

Taylor, J.C., H.P. Johnson, 1973. Gully Bank Erosion: Mechanics and Simulation by Digital Computer National Technical Information Service as PB-227 017, Iowa Water Resources Reserach Institute, Ames, Completion Report ISWRRI-48., 163 p.

Tourbier, J., R. Westmacott, 1974. Water Resources Protection Measures in Land Development, A Hand Book. University of Delaware Water Resources Center, Newark.

Turnbull, W.S., 1968. Construction Problems Experienced with Loess Soils in Conference on Loess: Design and Construction. Highway Res. Board Vol. 212, p. 10-27.

U.S. Corps of Engineers, 1980. Water Resources Investigation, St. Louis Metropolitan Area Missouri and Illinois, Maline Creek, Missouri Survey Report. Department of the Army, St. Louis District COE, St. Louis, Missouri.

U.S. Department Agricultural Soil Conservation Service, 1975. Standards and Specifications for Soil Erosion and Sediment Control in Developing Areas. College Park, Maryland.

U.S. Environmental Protection Agency, 1971. Control of Erosion and Sediment Deposition From Construction of Highways and Land Development. Vol. 1, Final Report.

U.S. Environmental Protection Agency. Results of the Nationwide Urban Runoff Program. Water Planning Division, 1983. Vol. 1, Final Report. Washington, D.C.

Water Resources Engineers, Inc. 1974. The San Francisco Stormwater Model for Computer Simulation of Urban Runoff Quantity and Quality in a Combined Sewer System, prepared for the Department of Public Works, City and County of San Francisco.

Williams, R.E., D.W. Allman, 1969. Factors Affecting Infiltration and Recharge in a Loess Covered Basin. J. Hydrol., Vol. 8, No. 3, p. 265-281.

Wischmeier, W.H., C.B. Johnson, B.V. Cross, 1971. A Soil Erodibility Nomongraph for Farmland and Construction Sites. J. Soil and Water Conservation Vol. 26 No. 5, p. 189-193.

Wolman, M.G., 1975. Erosion in the Urban Environment. Hydrologic Sciences Bulletin, Vol. 20, No. 1, p. 117-125.

Wolman, M.G., 1964. Problems Posed by Sediment Derived From Construction Activities in Maryland. Water Pollution Control Commission, Annapolis, Maryland.

Wright-McLaughlin Engineers, 1971. Urban Storm Drainage Criteria Manual (Volume 1 and 2), prepared for the Denver Regional Council of Governments, Colorado.

Wright-McLaughlin Engineers, 1982. Supplemental Report: Cost of Erosion Control Measures. Prepared for Denver Regional Council of Governments. City of Denver, Denver, Colorado.

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